Building Concorde

FROM DRAWING BOARD TO MACH 2

TONY BUTTLER WITH
JEAN CHRISTOPHE CARBONEL

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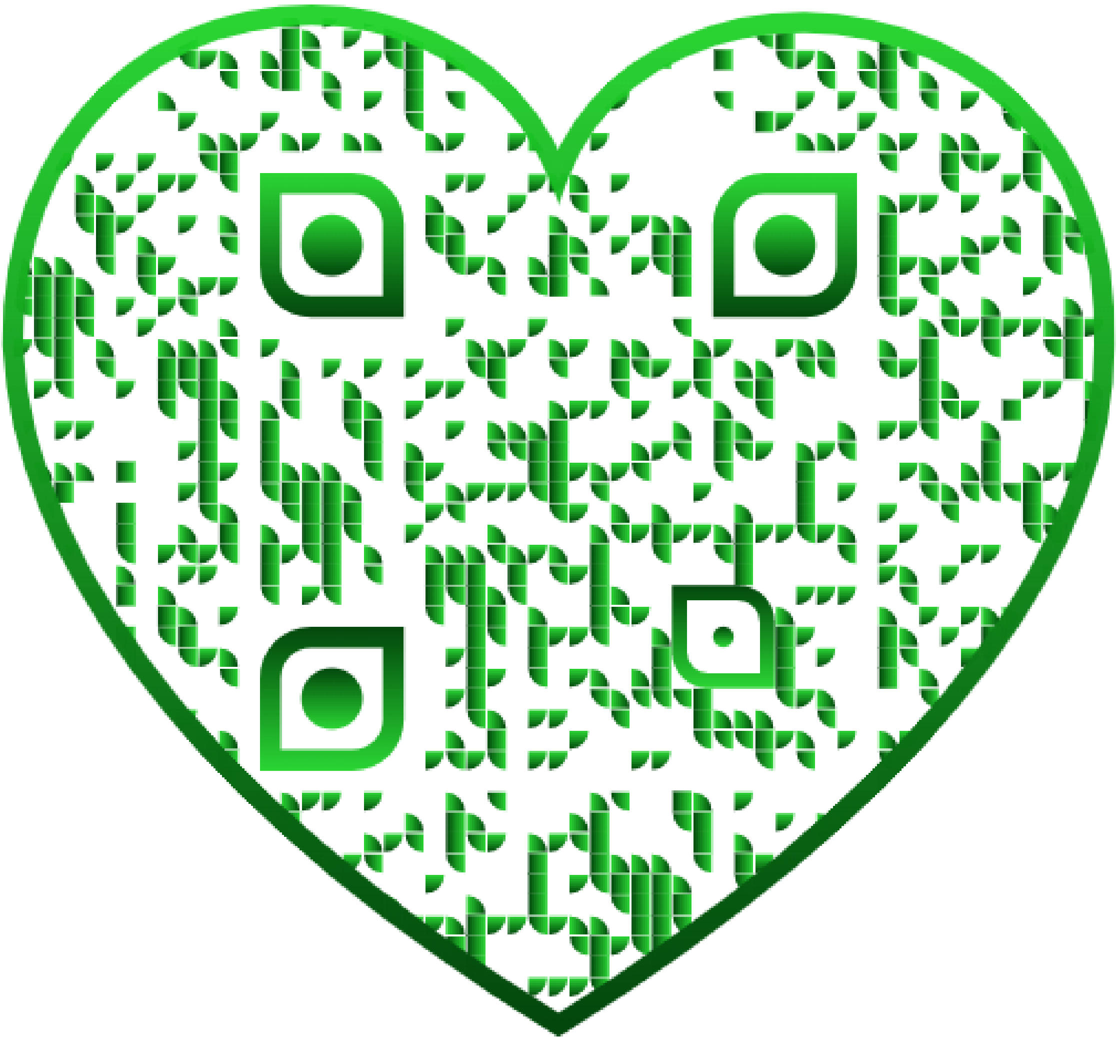

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Introduction

As a 13-year-old in 1969 I watched the first flight of Concorde with great interest, although my passion for aeroplanes was nowhere near as strong then as it is now. I feel so lucky to have been around to have witnessed it, if only on TV. It was a great thrill when I was asked to write about 'Building the Concorde' because the design and development of aircraft is the strongest area of my aviation interests, the supersonic element in particular is fascinating to me, and Concorde just has to be the most glamorous and most beautiful of all aeroplanes. How can one lose? Well, it is of course up to the readers to decide whether this book is a winner or not, but I certainly hope you will find reading it worthwhile.

Initially this was intended to be a solo effort, but I asked Jean-Christophe Carbonel to look into the French side of the story since this is not well known at all in the UK. As a result JC has undertaken a considerable amount of research in France and then contributed major sections of text to the narrative, including Chapter Three in its entirety. I am immensely grateful to JC for doing such a wonderful job here and in the process he has produced an account which, we understand, has never been seen in such depth in the English language before. In fact we also think that the early gestation of the Super Caravelle and Concorde has never really been covered in such depth in French language publications either.

You will not find any criticisms here – "why was this not done, or it was a mistake to build the aircraft". No, this book is the result of a long trawl through the archives for original documents and pictures in an attempt to present just some of what happened. It is not a complete history, but it does attempt to highlight the most critical issues involved in developing one of the world's only supersonic transports. And not everyone liked the aircraft of course, as illustrated by the level of protest prior to its service entry in the 1970s. Some of the information and stories here will be familiar to many readers I am sure, but other parts should be new.

Many of the British and French aircraft and engine designers and engineers who created Concorde are no longer with us, but they left their mark on history with a remarkable machine. Sadly that stunning white shape is no longer visible in a blue sky and now can only be seen on the ground, having been retired in 2003. In fact when Concorde was retired from service it was perhaps the first occasion when aviation took a backward step – never again will many of us have the chance to cross the Atlantic in just three hours! This is a fascinating story and I feel very privileged to have had the chance to write something about it!

Tony Buttler MA AMRAeS

ACKNOWLEDGEMENTS

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Adrian Balch; Luc Berger (Dassault); Dave Birch (Rolls-Royce Heritage Trust); Phil Butler; Jeremy Collins; Sir George Cox; Richard Cudd; Richard Curtis; Geraint Davies; Ken Ellis; John Farley; Chris Gibson; Yefim Gordon; the late Peter Green; Duncan Greenman; Barry Guess and Trevor Friend (BAE SYSTEMS Heritage Farnborough); Bob Hercock and Jock Heron (Rolls-Royce Heritage, Filton); Barry James (Midland Air Museum); Alan Jenner; Richard Payne; Dominique Prot (Safran); Colin Rees (Aberdare Boys Grammar School archive); Philippe Ricco; Brian Riddle (Royal Aeronautical Society/National Aerospace Library); Graham Rood (Farnborough Air Sciences Trust); Philippe Van Lierde (Secrétaire Général of AIRBUS AIRitage); Tony Wilson (North West Heritage Group), and Zoe Watson (Bristol Aero Collection. Also to the staff of the British National Archives at Kew and the French National Archives at Pierrefitte. And special thanks must go to JC for his research and writing.

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1

Origins and Studies – Britain

Beautiful photo of a beautiful aeroplane. BAC Concorde prototype 002 G-BSST is seen taxying ready for take off. *BAE SYSTEMS Heritage, Farnborough*

The concept of a civil airliner or transport aircraft capable of prolonged supersonic performance first came to the fore in British official circles during the 1950s. The 'Sound Barrier' was first breached on 14 October 1947 by the American Bell X-1 research aircraft, but it was to be well into the 1950s before supersonic flight by military types would become a common occurrence. At a time when crossing the Atlantic by piston airliner took the best part of a day, the possibilities for designing and building a Supersonic Transport or SST must have been considered by aircraft designers worldwide. But from a British point of view it was the establishment of a small committee at the Royal Aircraft Establishment (RAE) at Farnborough, to examine what might be possible in the SST field, which started to bring things together. However, this was well after the very first supersonic airliner study known to the author had been proposed by the Miles Company at Woodley, though the small project described here was produced at a time when no aircraft, not even a research type, had flown above Mach 1 – the speed of sound!

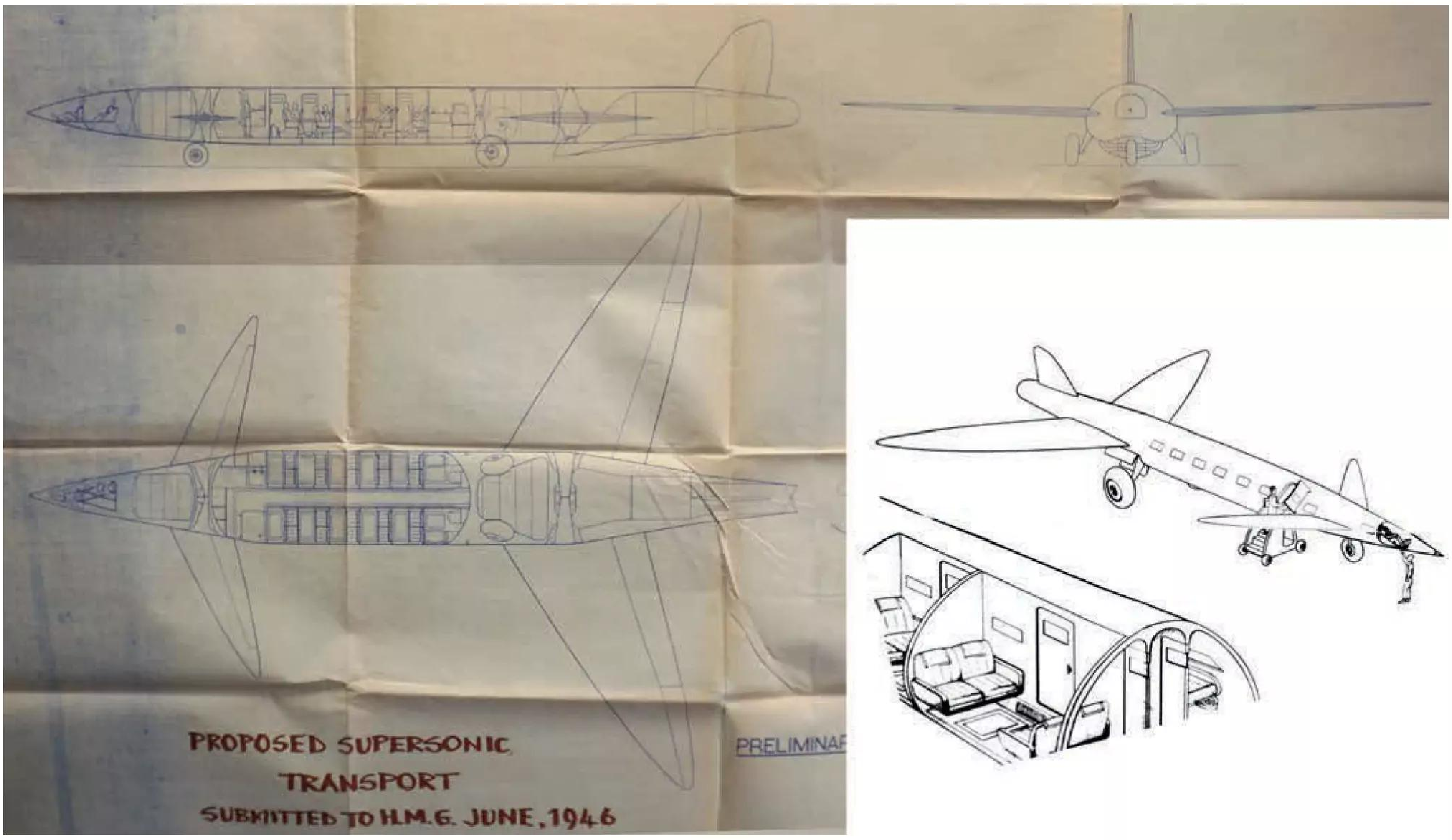
MILES SUPERSONIC AIRLINER

In June 1946 Miles Aircraft proposed a supersonic airliner design to the British Government. Using its design experience with the development of the M.52 supersonic research aircraft (abandoned in February 1946 before the first example had been completed) the manufacturer produced what was almost certainly the first such design drawn in the UK. This exotic-looking project was intended to carry 20 passengers and make use of the tandem wing Libellula arrangement (favoured by Miles in several other prototypes and projects) with a large span forward wing together with a main wing.

The manufacturer had considered that an interesting investigation would be to see whether a passenger-carrying aeroplane capable of four hours of flight at 1,000mph (1,609km/h) at 36,000ft (10,973m) altitude was a practical proposition. While it was found that this was indeed quite practical, it was also apparent that certain features had to be seriously considered for supersonic flight – in particular the fuselage frontal area had to be reduced to the absolute minimum to keep the drag as low as possible above Mach 0.9.

The Libellula arrangement appeared to offer several advantages:

a) the front wing had to operate at a much higher lift coefficient than the rear one for stability. Using wings of similar characteristics, therefore, it was obvious that the large rear wing was at no time operating at its maximum Cl



Miles supersonic transport (6.46). *Jim Pratt and Miles Archive*

value, because before this condition was reached the front wing would be stalled. If the wing section was high speed or supersonic, which normally had very low Cl values, the fitting of high lift devices became extremely advantageous. Consequently, using boundary layer suction or some other form of high lift device on the small front wing to increase its Cl maximum value automatically gave around a two-fold increase on the larger rear wing without any additional penalty.

(b) The centre of gravity could be much further aft than with a normal design, which meant that the powerplant could be installed at the extreme rear end of the fuselage.

(c) The aircraft would not be so susceptible to centre of gravity (cg) changes during flight and would accommodate the large centre of pressure variations found with the type of wing section used much more satisfactorily than with an orthodox layout.

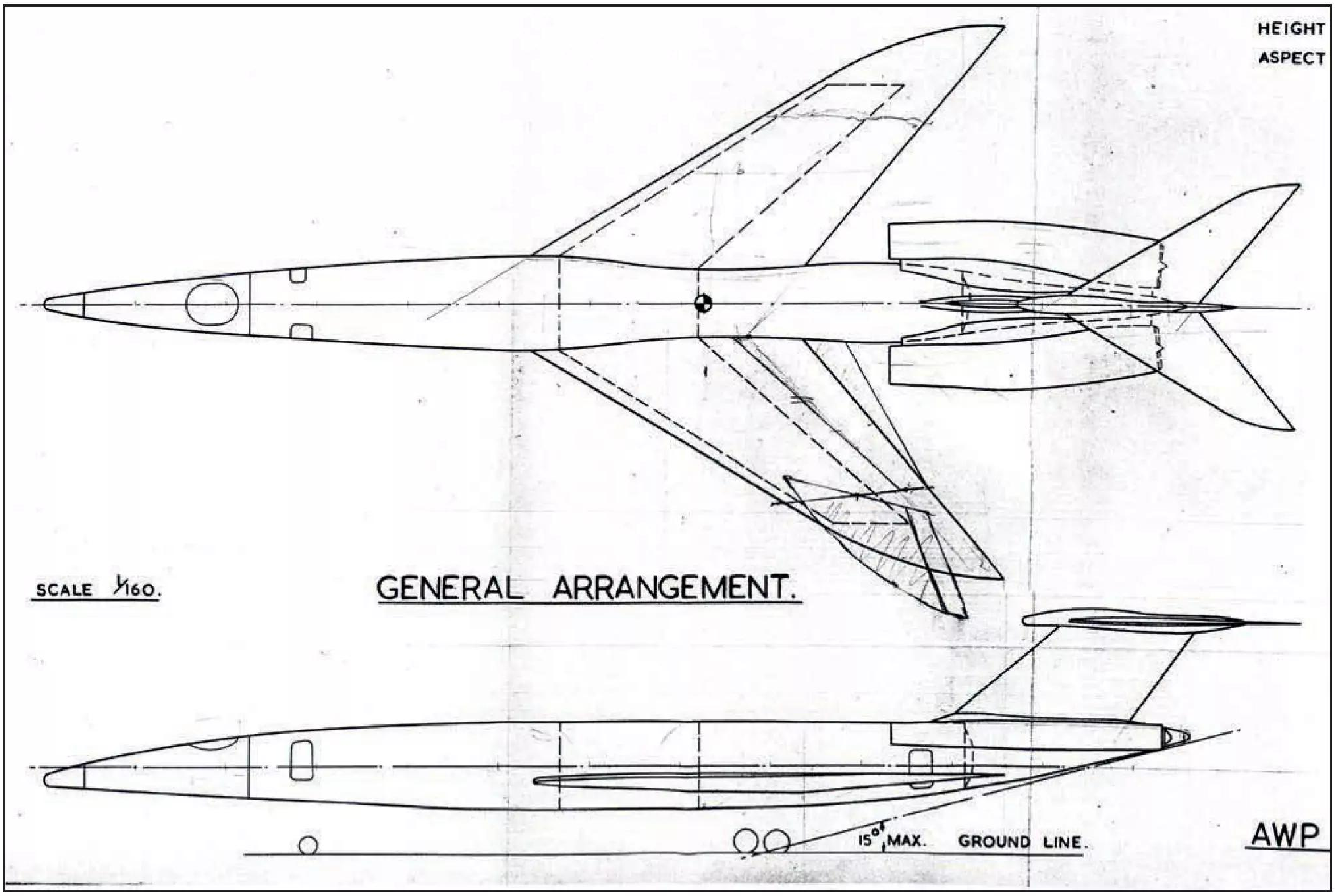
(d) Reduced surface areas could be used, improving overall drag during high-speed flight.

The design had a tricycle undercarriage and a single engine based on a Power Jets design giving 15,000lb (66.7kN) of thrust at 1,000mph (1,609km/h) at 36,000ft (10,973m). Its fuselage was to be a light hollow shell containing 1,250gal (5,684lit) of fuel in a forward tank and 3,000gal (13,641lit) in a main tank, which with another 1,750gal (7,957lit) in the wings gave 6,000gal (27,281lit) in all. Needless to say, this incredibly advanced project for its day was not taken up.

Austrian Ernst Mach was the first person to observe that airflow began to behave differently as it approached the speed of sound. At sea level sound travels at approximately 660 knots/760mph (1,223km/h) (a figure which varies slightly with temperature) while between 50,000ft and 60,000ft (15,240m and 18,288m) the speed drops to around 573 knots/660mph (1,062km/h).

When an aircraft flies at speeds of below about 300 knots (345mph/556km/h), the air flows over it in the manner of an incompressible fluid such as water, but once this figure has been exceeded the air molecules start to become compressed. As the aircraft approaches and then passes through into supersonic flight the air molecules have little time to rearrange themselves before it arrives, so a compression wave or shock wave piles up at the front of the aircraft. And at the rear of an aircraft travelling supersonically there will be a second wave that sees the air reverting to its normal form. The two supersonic shock waves resemble a ship's bow and stern waves and on the ground are usually heard as a double boom. In fact when close to the human ear these shocks sound like a violent bang, just like a clap of thunder, and like thunder over a distance they then coalesce into a dull boom. Mach's work is acknowledged by the term 'Mach number', which for an aircraft equates to the ratio of its flying speed to the speed of sound in air. So when an aeroplane's speed is exactly at the speed of sound it is then flying at Mach 1.

Mid-1950s proposals for large supersonic bombers, it may be assumed, boosted any thoughts by aircraft designers and manufacturers on the possibility of building a similarly-sized SST. In addition during the first years of the decade



The Armstrong Whitworth conventional wing design as detailed in report R-240 (7.58). *National Aerospace Library*

new fighter designs around the world were exploring the problems of transonic flight, the speed range in which an aircraft has air flowing over it at both subsonic and supersonic velocities. Then in 1954 the UK flew both the English Electric P.1 and Fairey Delta 2, fighter and research prototypes which now enabled true supersonic flight on the level to be explored, and in March 1956 the Delta 2 demonstrated its potential by breaking the World Air Speed Record by a huge margin with a figure of 1,132mph (1,821km/h), Mach 1.73.

In the meantime the small committee at RAE Farnborough had in 1954 presented its conclusions, including the statement that an aircraft could be developed to take just 15 passengers from London to New York at Mach 2. At a meeting at Shell-Mex House in London, called on the 1 October 1956 by Sir Cyril Musgrave, the Permanent Secretary of the Ministry of Supply (MoS), it was agreed that a co-operative research effort should be directed towards the eventual development of a supersonic civil transport aircraft.

A more concrete step followed on 5 November 1956 with the establishment of a steering committee called the Supersonic Transport Aircraft Committee or STAC, the chairman of which was Morien Morgan from the RAE's Aerodynamics Department who had been working on supersonic flight and design for some years already. Also on STAC came industrial representatives at chief designer level from most of the major aircraft and engine manufacturers, specialists from the RAE Farnborough and the National Gas Turbine Establishment (NGTE), representatives of the two British civil airline corporations, the Ministry of Transport and Civil Aviation and the MoS, the Air Registration Board, the Aircraft Research Association and the National Physical Laboratory.

Morgan would become one of the driving forces behind the SST concept and the STAC would hold regular meetings right through until March 1959. Industry confirmed that it would be able to make a substantial contribution to the work and the estimated expenditure at this stage was £690,000.

Earlier work at RAE had indicated that it might be possible to design a supersonic civil aircraft whose operating costs compared reasonably with subsonic aircraft such as the Boeing 707 and Douglas DC-8. Discussions went some way to confirming the practicability of such an aircraft, but at the same time emphasized the importance of an extensive research programme, which must be completed as soon as possible if the UK wished to be able to compete with the American civil aviation industry. This was particularly true for configurations designed to cruise in the region of Mach 1.2. Here the use of shock free wings to postpone a large part of the drag rise at supersonic speeds was a new concept backed by meagre experimental evidence. Although Mach 1.2 seemed at this stage to be the most promising speed to aim for on a long range transatlantic aircraft, the discussions were covering the range right up to about 1.8 since there was one body of opinion that favoured going for the highest speed permissible without encountering such kinetic heating temperatures as would necessitate abandoning light alloy construction.

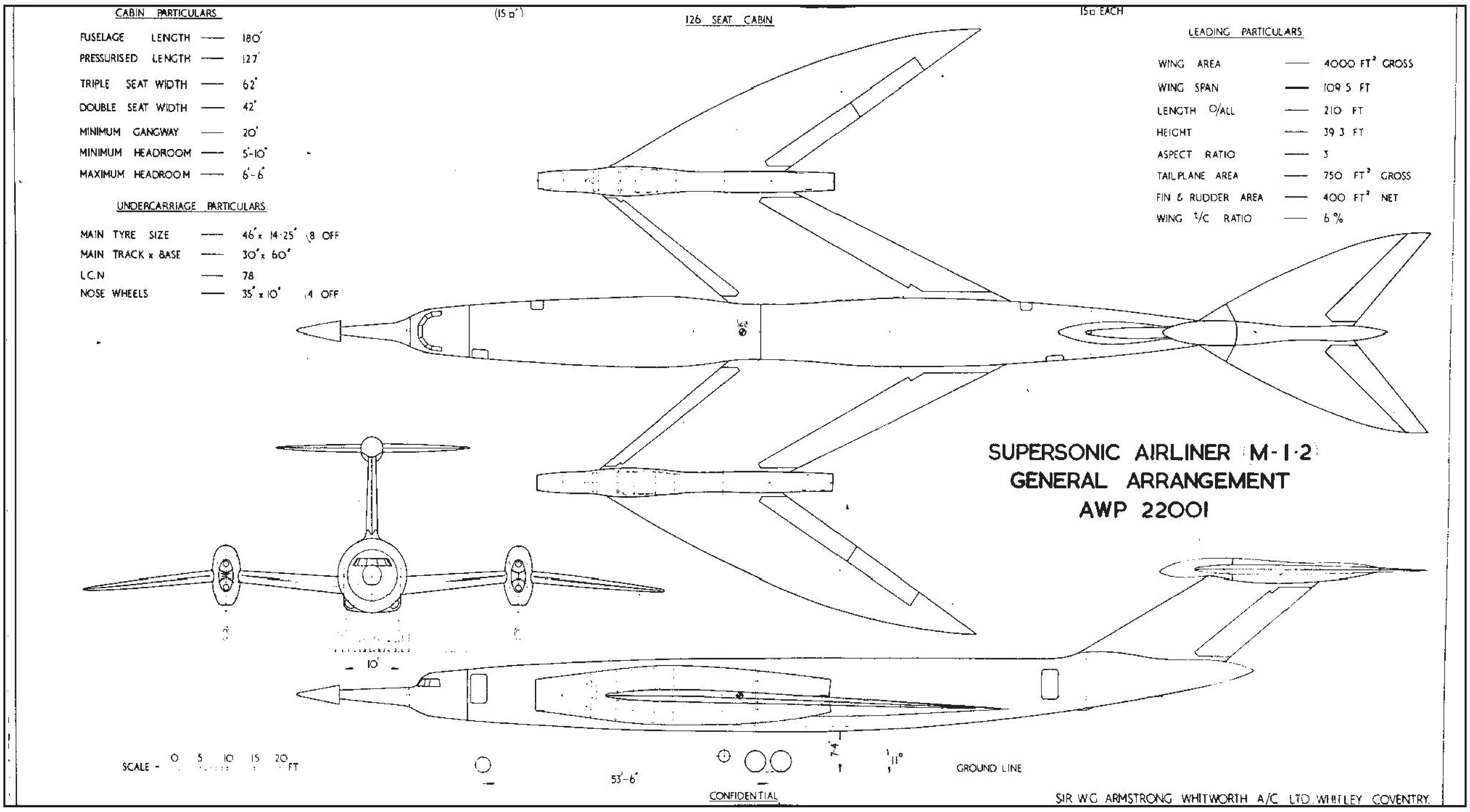
The major objective of the STAC was to work towards a single transport requirement and in doing so it would consult with its representatives of industry and with the customers who would hopefully buy the aircraft: the MoS and the two airlines – British European Airways (BEA) and British Overseas Airways Corporation (BOAC). Under the general guidance of Farnborough, a principal task was to gather basic data, pinpoint the technical issues of commercial supersonics and resolve delicate political and industrial issues.

The problems faced by the engineers of the 1950s in putting a supersonic transport into commercial service – without the aid of computers – were substantial to say the least. There were the obvious areas of structural materials and powerplants (to provide sufficient thrust and to find a means of silencing the powerful afterburning engines adequately if the aircraft was ever to be allowed to take off). But the high speeds at which an SST would fly brought for example new problems with more accurate weather forecasting, air traffic control, navigation and long-range communications. In addition, the cost of such aircraft would require a reduction in the time that they spent on the ground so as to achieve adequate utilisation. The speed range considered by STAC soon stretched from Mach 1.2 to Mach 2.6.

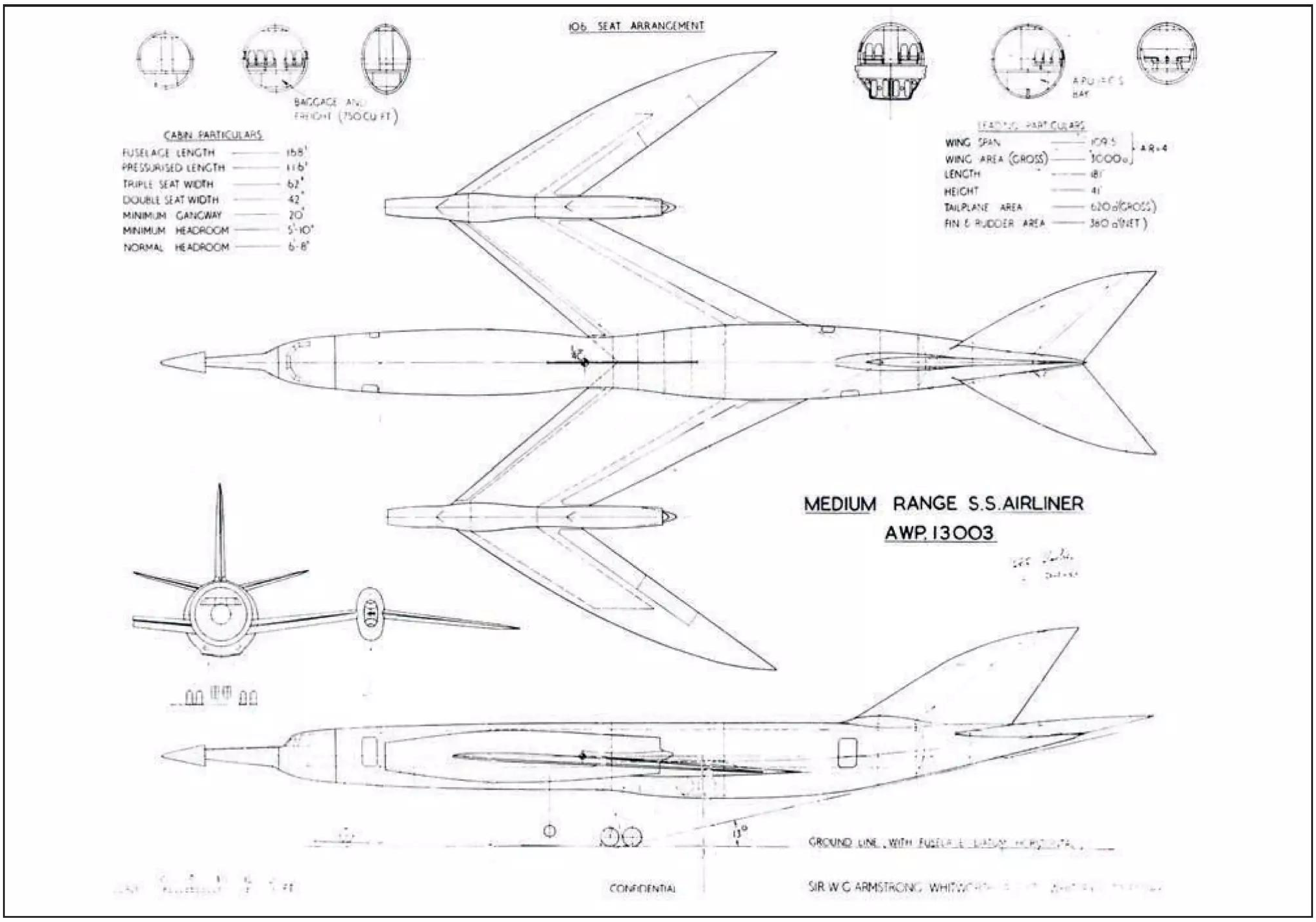
The committee funded research from a number of British aircraft manufacturers, resulting in design brochures offering a wide variety of configurations and wing shapes. From the start the aircraft manufacturers expressed their willingness to participate in a co-operative research effort, something which was considered to be a crucial point affecting this project. It was quite clear that research into the problems arising in this field demanded research capacity far beyond that which was available either in the Ministry, or in any single or small group of aircraft contractors. Only a combined approach could achieve results which might give the UK a lead over the Americans, who it was considered would be Britain's main and most dangerous competitor.

In February 1957 J.M. Ramsden of *Flight* magazine reported how "For a year or more Avro, Bristol, de Havilland, Handley Page, Rolls-Royce, Vickers-Armstrongs and other firms have had small initial project teams studying the supersonic transport. Each firm has pursued its own line of thought, and has come up against the same hard facts – that success, if it is to be achieved within 15 years, depends upon a programme of research and development so costly that the country could afford to support only a united effort upon one project (or *perhaps* two)."

Events would show that his statement was prophetic and in fact only one project would be followed with the developments and costs split between two countries. For the time being, however, the projects submitted by industry


CABIN PARTICULARS
FUSELAGE LENGTH — 180'
PRESSURISED LENGTH — 127'
TRIPLE SEAT WIDTH — 62"
DOUBLE SEAT WIDTH — 42"
MINIMUM GANGWAY — 20"
MINIMUM HEADROOM — 5'-10"
MAXIMUM HEADROOM — 6'-6"
UNDERCARRIAGE PARTICULARS
MAIN TYRE SIZE — 46" x 14·25" (8 OFF
MAIN TRACK x BASE — 30' x 60'
L.C.N — 78
NOSE WHEELS — 35" x 10" (4 OFF
(15 □')
126 SEAT CABIN
15 □ EACH
LEADING PARTICULARS
WING AREA — 4000 FT² GROSS
WING SPAN — 109·5 FT
LENGTH O/ALL — 210 FT
HEIGHT — 39·3 FT
ASPECT RATIO — 3
TAILPLANE AREA — 750 FT² GROSS
FIN & RUDDER AREA — 400 FT² NET
WING t/c RATIO — 6 %
SUPERSONIC AIRLINER M-1·2
GENERAL ARRANGEMENT
AWP 22001
10'
53'-6"
11°
GROUND LINE
SCALE - 0 5 10 15 20 FT
CONFIDENTIAL
SIR W.G. ARMSTRONG WHITWORTH A/C LTD. WHITLEY COVENTRY.

Armstrong Whitworth M-wing design – Report R-252 (12.58). *National Aerospace Library*


106 SEAT ARRANGEMENT
BAGGAGE AND FREIGHT (750 CU FT)
A.P.U. & E.S BAY
CABIN PARTICULARS
FUSELAGE LENGTH — 158'
PRESSURISED LENGTH — 116'
TRIPLE SEAT WIDTH — 62"
DOUBLE SEAT WIDTH — 42"
MINIMUM GANGWAY — 20"
MINIMUM HEADROOM — 5'-10"
NORMAL HEADROOM — 6'-8"
LEADING PARTICULARS
WING SPAN — 109.5'
WING AREA (GROSS) — 3000□'
AR=4
LENGTH — 181'
HEIGHT — 41'
TAILPLANE AREA — 620□'(GROSS)
FIN & RUDDER AREA — 380□'(NET)
MEDIUM RANGE S.S. AIRLINER
AWP. 13003
13°
GROUND LINE, WITH FUSELAGE DATUM HORIZONTAL
CONFIDENTIAL
SIR W.G. ARMSTRONG WHITWORTH

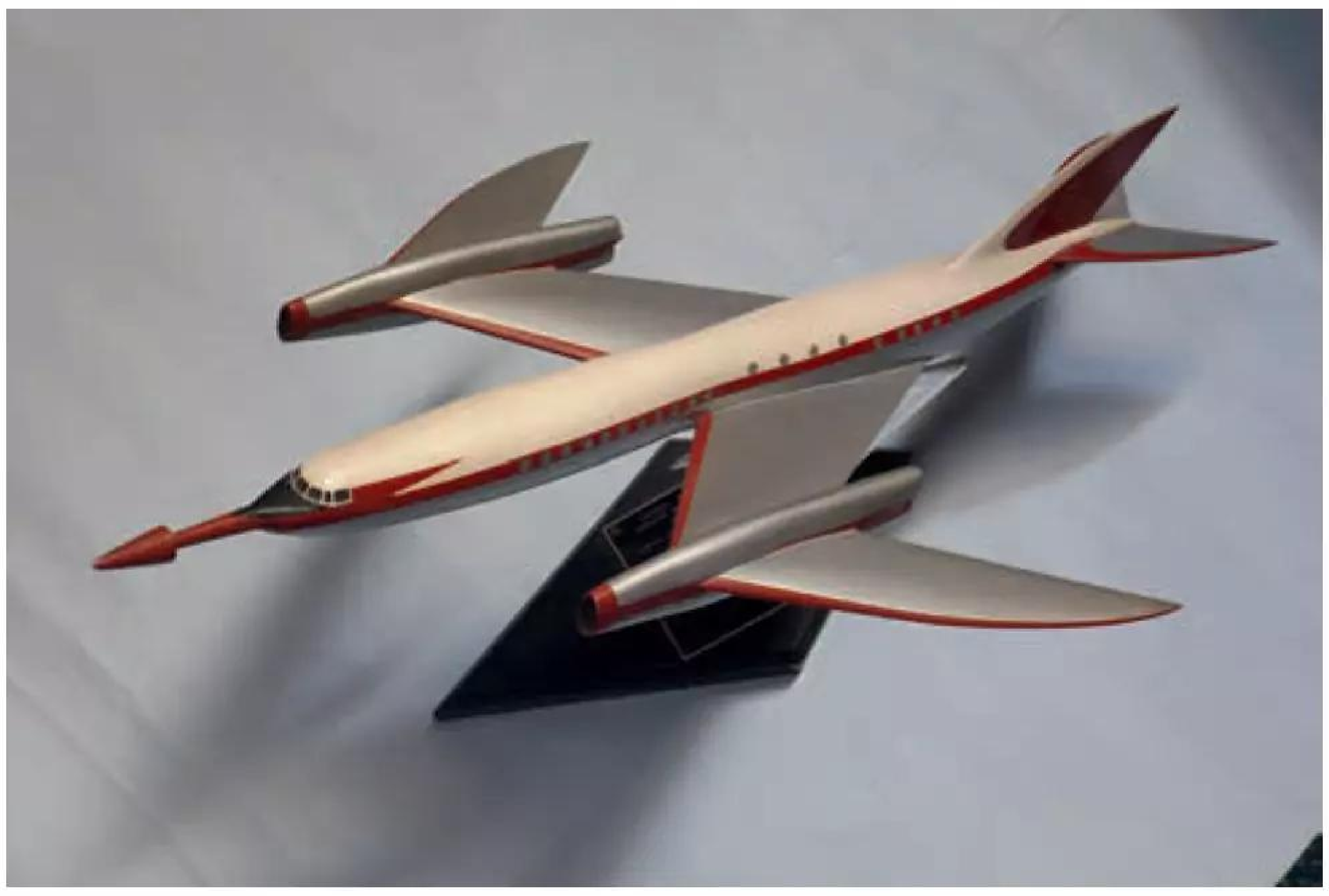
Armstrong Whitworth M-wing design – Report R-261 (1959). The brochure artwork showed the aircraft with the designation AWP13, which also appears on the model stand. *National Aerospace Library*

included the following (not included here is what appears to have been a brief study from Fairey, Project 91, of December 1958 which would have seated 120).

AWA CONVENTIONAL WING (REPORT R-240)

During the 1940s and 1950s Armstrong Whitworth Aircraft (AWA) had shown considerable flair in terms of producing new designs with unusual and advanced wing shapes, not least with the AW.52 flying wing research aircraft. In terms of SST research, the firm is remembered for its M-wing layouts, but to begin with the study described here used a much more conventional wing.

During the first half of 1958 the firm's Project Section conducted design studies to assess the respective merits of two medium-range, Mach 1.2-cruise airliners. One had the 'M' planform described shortly, but this project had a tapered, swept-back wing. AWA declared that there were three main advantages which the swept wing held over an untapered constant lift coefficient wing of equivalent thickness-chord ratio and aspect ratio: a) lower structure weight, b) lower induced drag factor at sub-critical speeds and c) less tendency to pitch-up if the flow separated from the leading edge.



Model of the AWA AWP13 M-wing proposal (Report R-261), a prized exhibit in the hands of the Midland Air Museum at Baginton. *Barry James, Midland Air Museum*

The reduction in structure weight would enable a larger payload without increasing all-up weight, thereby leading to a reduction in direct operating costs. The main disadvantage was the spanwise variation of lift.

The engines, based on an NGTE design, were housed in pairs at the rear of the fuselage in order to obtain an undisturbed airflow over the wing. This gave the additional advantage of being quieter and less likely to cause airframe fatigue; however, this engine layout was tentative – dependent on test results from the RAE. Two four-wheel bogies formed the main undercarriage and this aircraft was designed to carry 100 passengers plus 3 crew over a stage length of 1,500nm (2,778km) at Mach 1.2. Gross still-air-range was taken as 2,500nm (4,630km). The term 'stage length' referred to the length of the average flight operated by a particular airline.

AWA M-WING (REPORT R-252)

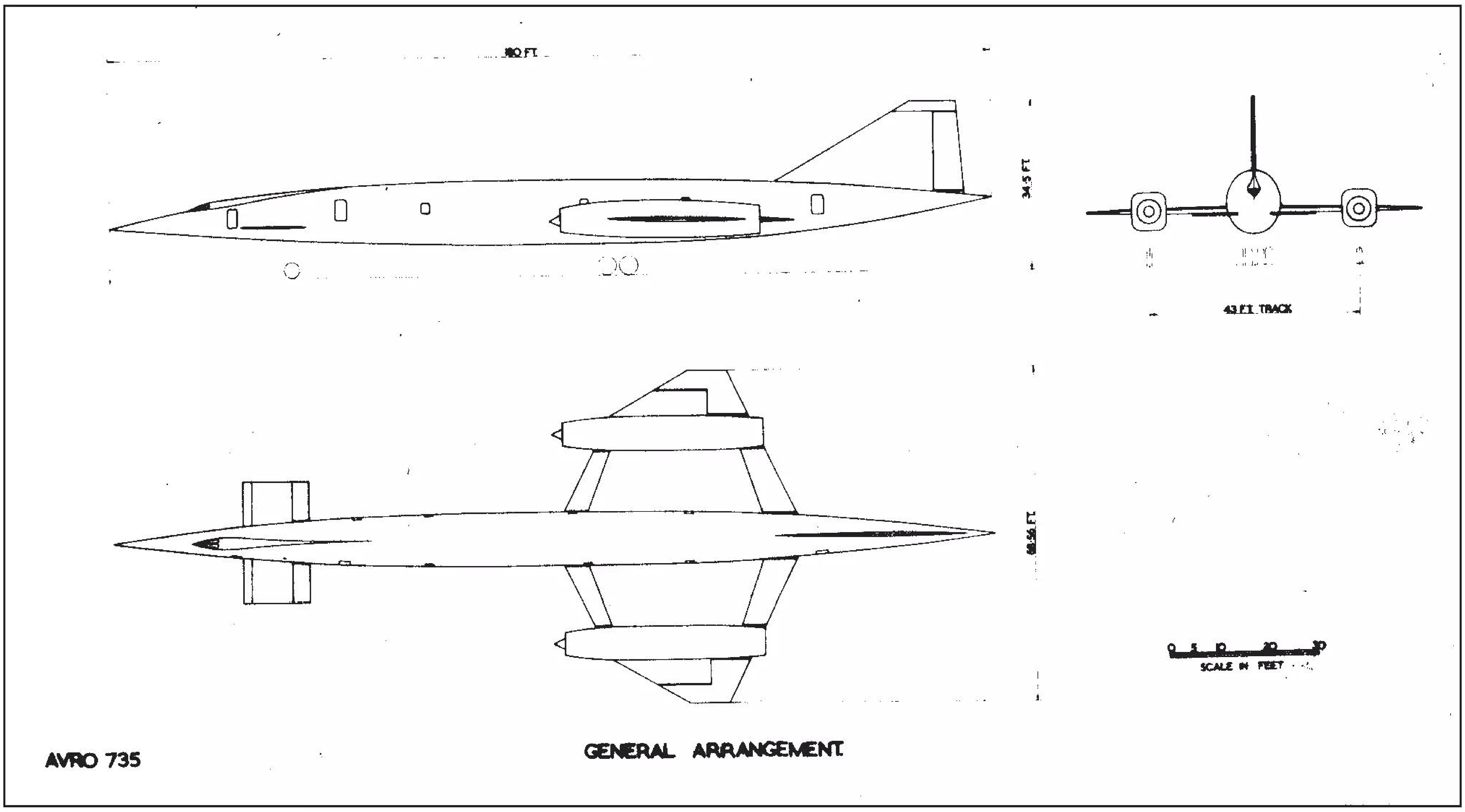
In January 1957 a preliminary project study had been made by AWA for an M-wing 120-passenger Mach 1.2 transport with a stage length of 3,000nm (5,556km). A follow-on report R-252 issued in December 1958 detailed an M-wing transport designed to carry 126 passengers over the same stage length with cruise again at Mach 1.2. This aircraft's balanced field length (the shortest runway length to comply with safety regulations) was estimated to be 10,300ft (3,140m), and the landing approach speed was 134 knots (248km/h).

When considering the take-off performance of the earlier optimum aircraft of 1957, which had a wing area of 3,600sq ft (334.80sqm), it had been found that this design did not meet the 11,000ft (3,353m) balanced field length requirement. Consequently, the wing area for this later study had been increased to 4,000sq ft (372sqm), a move which had been shown to have little effect on the aircraft's direct operating costs. For this wing arrangement the engines were mounted in pairs, one above the other, in wing nacelles at the mid-semi-span of the M-wing. Two four-wheel bogies formed the main gear of a bicycle undercarriage with four smaller wheels under the nose and undercarriage outriggers beneath the engine nacelles.

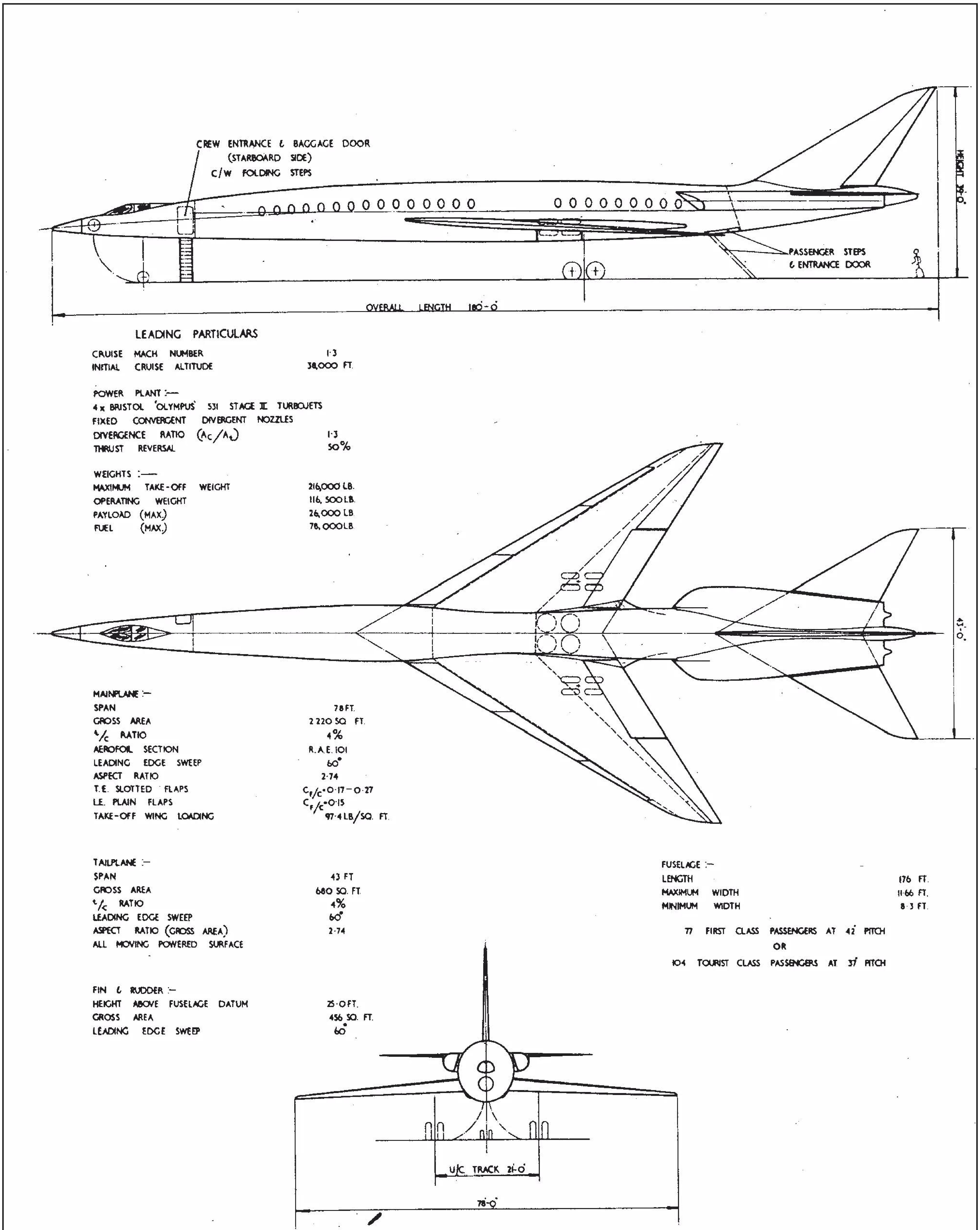
AWA M-WING (REPORT R-261)

STAC's interest in a medium range airliner with 100 passengers and low Mach supersonic cruise had been aroused because BEA had favoured a Mach 1.2-1.3 aircraft rather than a type capable of Mach 1.8. This was because the airline assumed that the supersonic airliner would have to operate within the existing air transport system, and even with some new modifications to this system there would still be occasions when the airliner would have to deviate from its design flight plan. If it had to fly shorter routes or make deviations, the impact on operating costs would be significant. The Mach 1.8 type was also likely to have poorer manoeuvrability, higher approach speeds and higher design cruising altitude.

It was with this knowledge that AWA made another M-wing design study in 1959 for a 100-passenger Mach 1.2 transport with a stage length of 1,500 miles (2,778km). Its design was based on the assumption that the wing and tail unit wave drag could be reduced by an estimated 75% by the M-wing arrangement. In addition, for this brochure a new approach had been made to the cockpit design. Previously an elevating cockpit had been considered necessary to give the pilot a sufficient field of view for take-off and landing, and to avoid a large drag penalty in the cruise condition. However, for this new design a sting



Avro 735 (1956). *Avro Heritage Centre*


CREW ENTRANCE & BAGGAGE DOOR
(STARBOARD SIDE)
C/W FOLDING STEPS
PASSENGER STEPS
& ENTRANCE DOOR
HEIGHT 38'-0"
OVERALL LENGTH 180'-0"
43'-0"
U/C TRACK 21'-0"
78'-0"

LEADING PARTICULARS

CRUISE MACH NUMBER	1·3
INITIAL CRUISE ALTITUDE	38,000 FT.

POWER PLANT :—

4 x BRISTOL 'OLYMPUS' 531 STAGE II TURBOJETS

FIXED CONVERGENT DIVERGENT NOZZLES

DIVERGENCE RATIO (A_c/A_t)	1·3
THRUST REVERSAL	50%

WEIGHTS :—

MAXIMUM TAKE-OFF WEIGHT	216,000 LB.
OPERATING WEIGHT	116, 500 LB.
PAYLOAD (MAX.)	26,000 LB.
FUEL (MAX.)	78, 000 LB.

MAINPLANE :—

SPAN	78 FT.
GROSS AREA	2 220 SQ. FT.
t/c RATIO	4%
AEROFOIL SECTION	R.A.E. 101
LEADING EDGE SWEEP	60°
ASPECT RATIO	2·74
T.E. SLOTTED FLAPS	$C_f/c = 0{\cdot}17 - 0{\cdot}27$
L.E. PLAIN FLAPS	$C_f/c = 0{\cdot}15$
TAKE-OFF WING LOADING	97·4 LB/SQ. FT.

TAILPLANE :—

SPAN	43 FT
GROSS AREA	680 SQ. FT.
t/c RATIO	4%
LEADING EDGE SWEEP	60°
ASPECT RATIO (GROSS AREA)	2·74

ALL MOVING POWERED SURFACE

FIN & RUDDER :—

HEIGHT ABOVE FUSELAGE DATUM	25·0 FT.
GROSS AREA	456 SQ. FT.
LEADING EDGE SWEEP	60°

FUSELAGE :—

LENGTH	176 FT.
MAXIMUM WIDTH	11·66 FT.
MINIMUM WIDTH	8·3 FT.

77 FIRST CLASS PASSENGERS AT 42" PITCH
OR
104 TOURIST CLASS PASSENGERS AT 37" PITCH

Short P.D.22 (4.57). *Richard Payne*

mounted nose cone ahead of a conventional subsonic type cockpit was used and the necessary field of view could be obtained from both pilots' seats by looking to one side or other of the sting. It was considered that this arrangement would give rise to only a slight increase in drag in the cruise condition. The final aircraft had its tailplane in a low position and not at the top of the fin as assumed previously in design R-252.

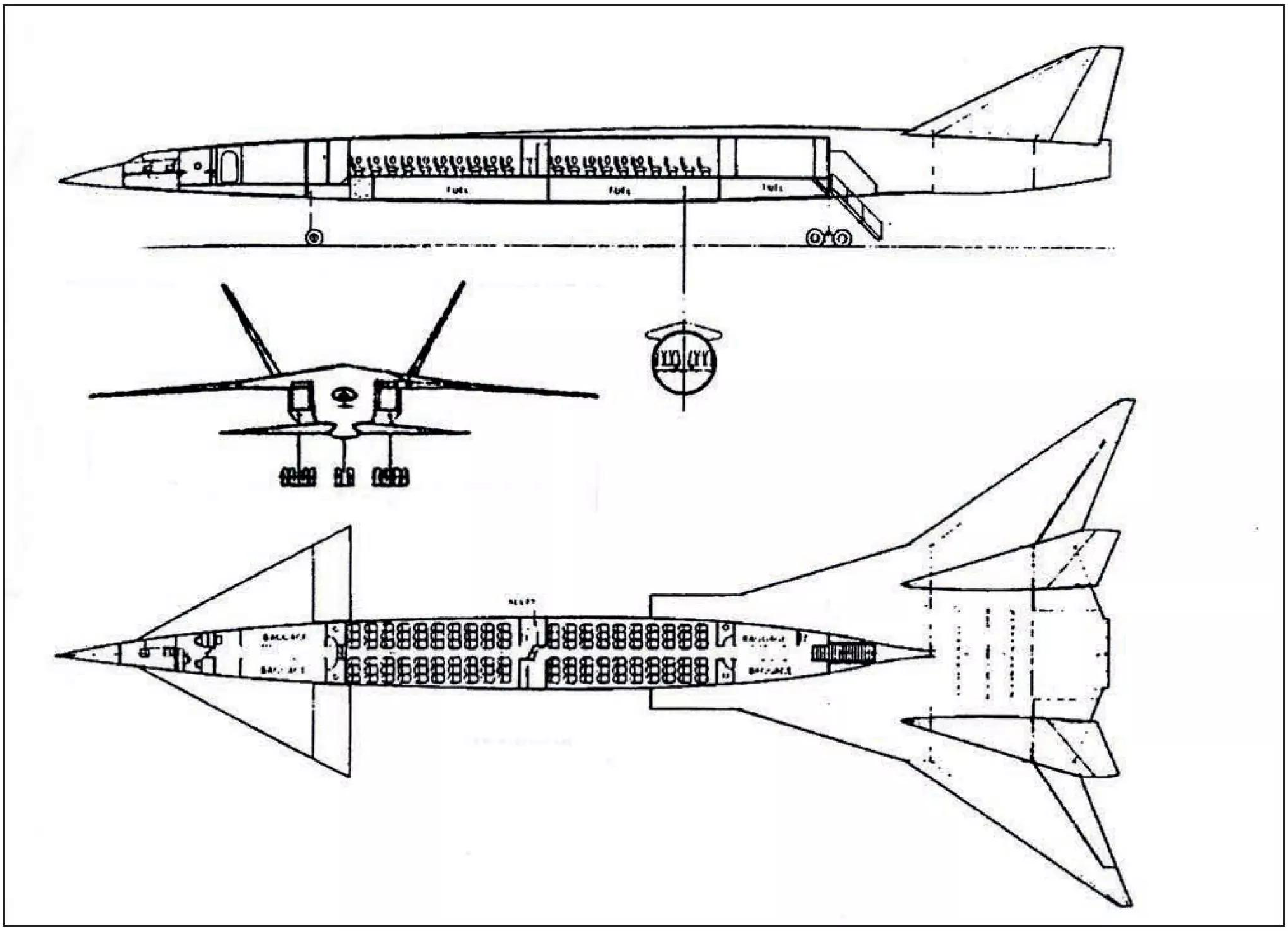
AVRO 735

Avro's 735 proposal was clearly based on the company's Type 730 supersonic high-altitude reconnaissance bomber design in its final Mach 2 form, before that project was abandoned in 1957. The 735 featured a small all-moving noseplane with nose flaps and trailing edge elevators, both of which used boundary layer control, and according to the drawing power came from eight NGTE-type jet engines mounted in blocks of four in each wing nacelle. These nacelles had variable-geometry intakes and variable convergent/divergent nozzles. Other sources suggest a powerplant of eight Armstrong Siddeley P.176 engines had originally been earmarked for the aircraft. The wing itself had trailing edge flaps again with boundary layer control. A total of 14,300gal (65,021lit) of fuel was to be carried in large wing tanks and in three more situated in the lower rear fuselage directly to the rear of the main landing gear, and this volume gave a range of 1,500nm (2,780km). A bicycle undercarriage was employed with outriggers in the engine nacelles. Operating height was between 40,000ft (12,192m) and 50,000ft (15,240m).

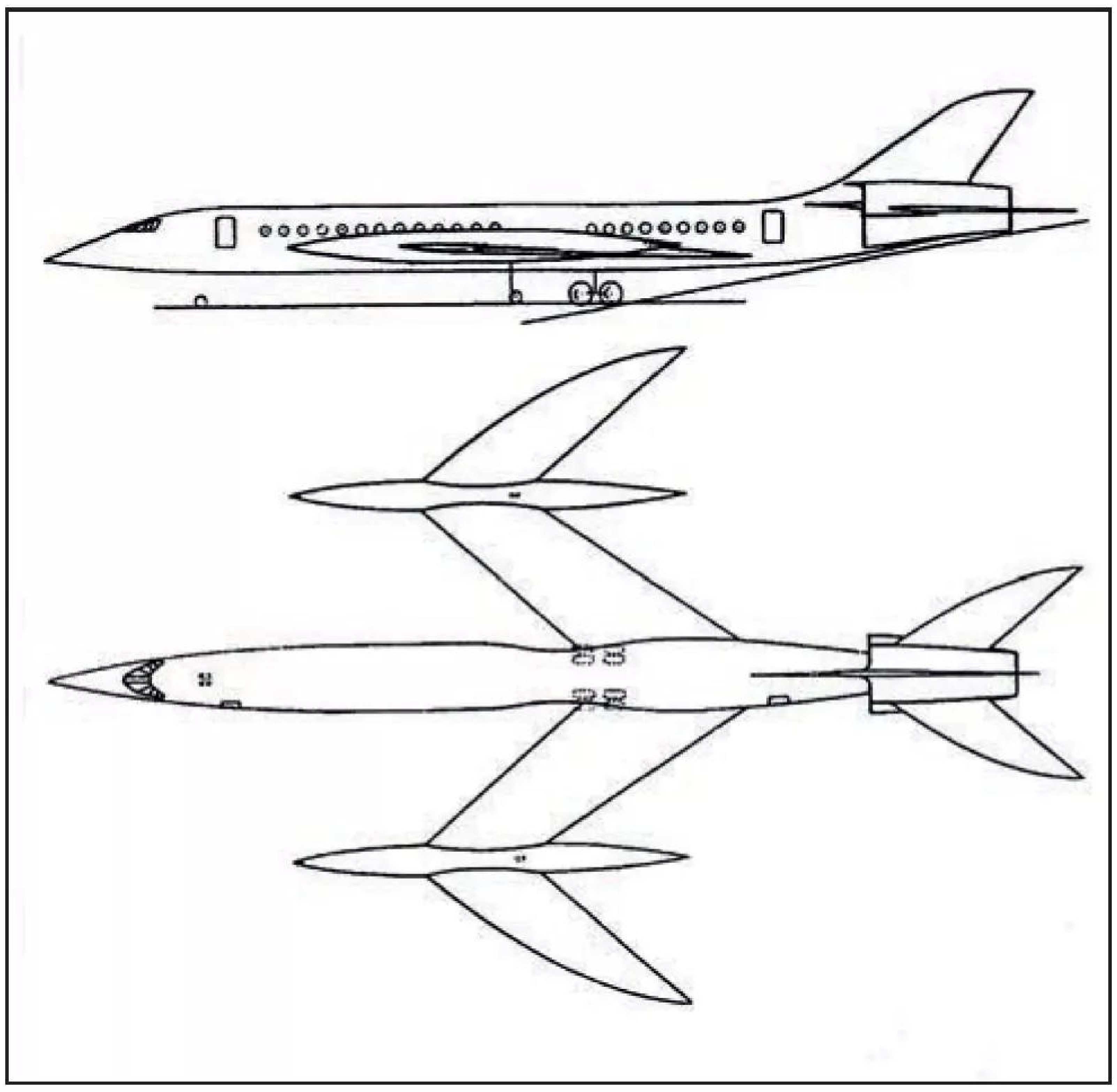
In addition, during 1958 Avro looked at an integrated wing supersonic airliner design under its Type 760 designation. This was to be powered by six engines and would carry 186 passengers.

BRISTOL TYPE 198

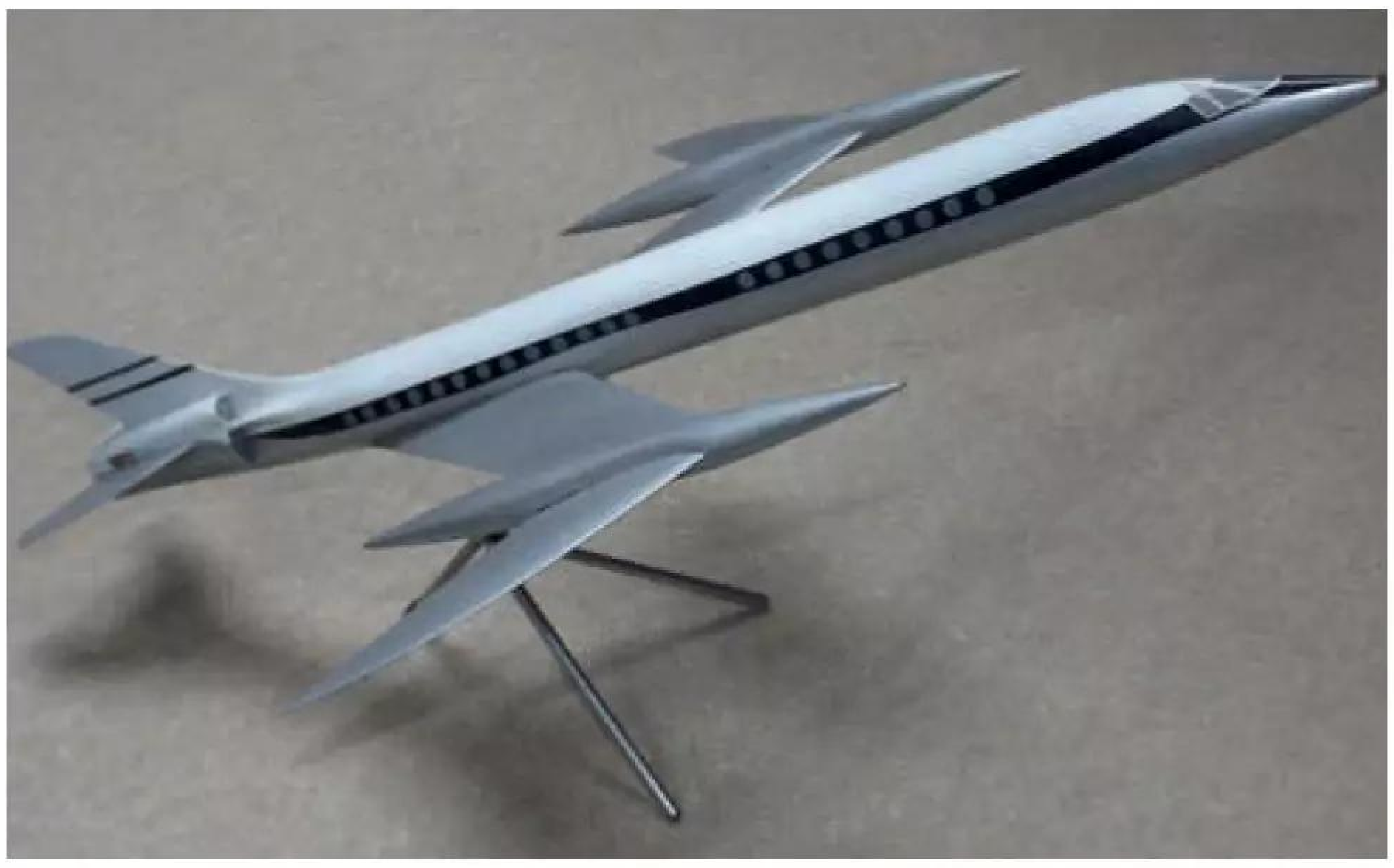
This first offering from Bristol, dated February 1957, can perhaps be considered the starting point for the Concorde itself, since the firm's final design effort would be integrated into the aircraft as built. The original Bristol Type 198 brochure described a preliminary assessment of a possible 100-passenger Mach 1.2 short range civil transport to STAC standards. It had a still air range of 2,500nm (4,630km) with a 1,500nm (2,778km) stage. Its wing was of a compound M and W planform having two kinks on each side (designed to have shock free flow at Mach 1.2) and the engines (of an



Short P.D.29 (4.59). *Richard Payne*



Vickers Project X (10.56). *Richard Payne*



Model of the M-wing project that was assessed within the Vickers Project X research. *BAE SYSTEMS Heritage, Farnborough*

unknown type) were mounted beneath the rear section of the wing at the end of the inner crank.

For aeroelastic reasons the kink of a W-wing should have been at over 50% of the semi span, but to use such a wing with the engines at the rear of the kink would have imposed severe balance problems (making the engine cut case difficult) and pose difficult undercarriage stowage problems. It had therefore been decided to put the kink fairly close to the body and to turn back the tips to alleviate the aeroelastic problem, thereby producing a double cranked wing. Mean wing sweep angle at quarter chord was 60°. The fuselage was of a double bubble cross section, the lower section containing the holds for freight, and the aircraft had a droop nose to improve the aircrew's view at low speeds.

The study concluded that the 2,500nm (4,630km) range could be met by an aircraft of 169,000lb (76,658kg) all-up-weight. At this weight the field length required International Standard Atmosphere (ISA) conditions at sea level was 6,900ft (2,103m), and the landing distance 6,950ft (2,118m) at 130,000lb (58,968kg) weight with an approach speed of 135 knots (250km/h). Bristol considered that it was probable that flap blowing would be needed to achieve the landing speed.

SHORT P.D.22

During the late 1950s Short Brothers prepared several designs for SSTs, the first of which was the P.D.22. This was a medium range project prepared for BEA and it featured a highly swept mid-position wing, a 'waisted' or area-ruled fuselage, four engines mounted alongside and within the rear fuselage, two fuel tanks and two bays for freight in the lower fuselage, and a narrow track tricycle undercarriage. The airframe was to be built mostly in high strength aluminium alloys and carried 72,000lb (32,659kg) of fuel. The wing was swept 60° at the leading edge, it featured plain leading-edge flaps and slotted trailing edge flaps, and the engines had 50% thrust reversal and fixed convergent divergent nozzles. P.D.22 was designed to operate out of 7,500ft (2,286m) runways and had a range of 1,500nm (2,780km).

SHORT P.D.29

The larger and faster P.D.29 appeared two years later and the most promising of several arrangements considered under this designation introduced a large foreplane for trimming, a cranked delta wing and twin fins. The foreplane also reduced drag and the aircraft had a range of 4,600nm (8,524km) with its fuel housed in the lower fuselage. Balanced field length was 9,000ft (2,743m). Shorts SST studies also embraced the P.D.30 designed for long range and Mach 1.8 performance, and a separate Mach 1.5 project which also carried enough fuel for long range operations.

VICKERS PROJECT X

The two separate Vickers design teams, one at Weybridge and the former Supermarine organisation at Hursley Park, began a series of supersonic transport studies as early as October 1956 under the designation Project X. Work at Hursley Park involved high wing layouts with podded engines, while the team at Weybridge was another to look into the M-wing concept with designs intended to take 100 passengers between London and New York. This M-wing project had four engines mounted around the end fuselage, a waisted middle fuselage, and a bicycle undercarriage with an eight-wheel main unit plus outriggers in wing nacelles.

STAC RECOMMENDS

STAC's strong recommendation, made in March 1959, was that detail design work on two 'first generation' SSTs should be started, as follows:

1. A long-range supersonic transport capable of taking 150 passengers on non-stop London to New York operations

(i.e. a stage length of some 3,500 statute miles [5,630km]) and at a cruising speed of Mach 2. All-up weight was likely to be 350,000-500,000lb (158,760-226,800kg) and the runway requirement was set at 9,000ft (2,745m).

2. A shorter range (up to 1,500 statute miles/2,414km) 100-passenger Mach 1.2 SST to operate on Empire and European routes. Here the runway requirement was set at 7,000ft (2,135m).

It was proposed that one prototype and four development aircraft should be built. The amount of proving flying needed before a supersonic aircraft could enter service could be anything between 5,000 and 25,000 hours, depending on the degree of novelty in the design, manufacture or operation. Assuming contracts were awarded in January 1960, and the initial design studies had been completed by 1962, the airline in-service dates were given as 1971-1972 for the Mach 2 long-range type and 1968-1970 for the Mach 1.2 short-range type.

It was suggested that a supersonic transport aircraft might be suitable for RAF Transport Command, who could then undertake most usefully a considerable amount of the proving flying. STAC also concluded that aircraft cruising at speeds in the region of 1,700mph (2,735km/h) Mach 2.61 and above should be considered as the second generation of SSTs and could not be recommended in the near term, though research on designs for higher speeds should go on.

Cruising at Mach 3 presented huge technical problems due to kinetic heating, the build-up of heat on the airframe caused by friction as the aircraft passed through the air. The temperatures generated would be too much for an aluminium airframe, so a structure of titanium or steel or both would be necessary which would increase the cost by a substantial margin. Mach 1.8 was considered to be the speed at which no problems of thermal deterioration would arise with conventional aluminium alloys, while the aircraft as designed was to be based on a slender wing with rear mounted engines.

In April 1959 the MoS, Aubrey Jones, disclosed to Parliament these main recommendations from STAC's 260-page report and added that the proposals were being "carefully studied". In due course these recommendations were accepted and further feasibility studies were commissioned by the MoS from Bristol and Hawker Siddeley. Separate approaches for light alloy supersonic aircraft were to commence in September 1959, with Bristol concentrating initially on a 3,000nm (5,560km) stage length with around 110 passengers while Hawker Siddeley looked at a 2,200nm (4,075km) stage length with 80 passengers.

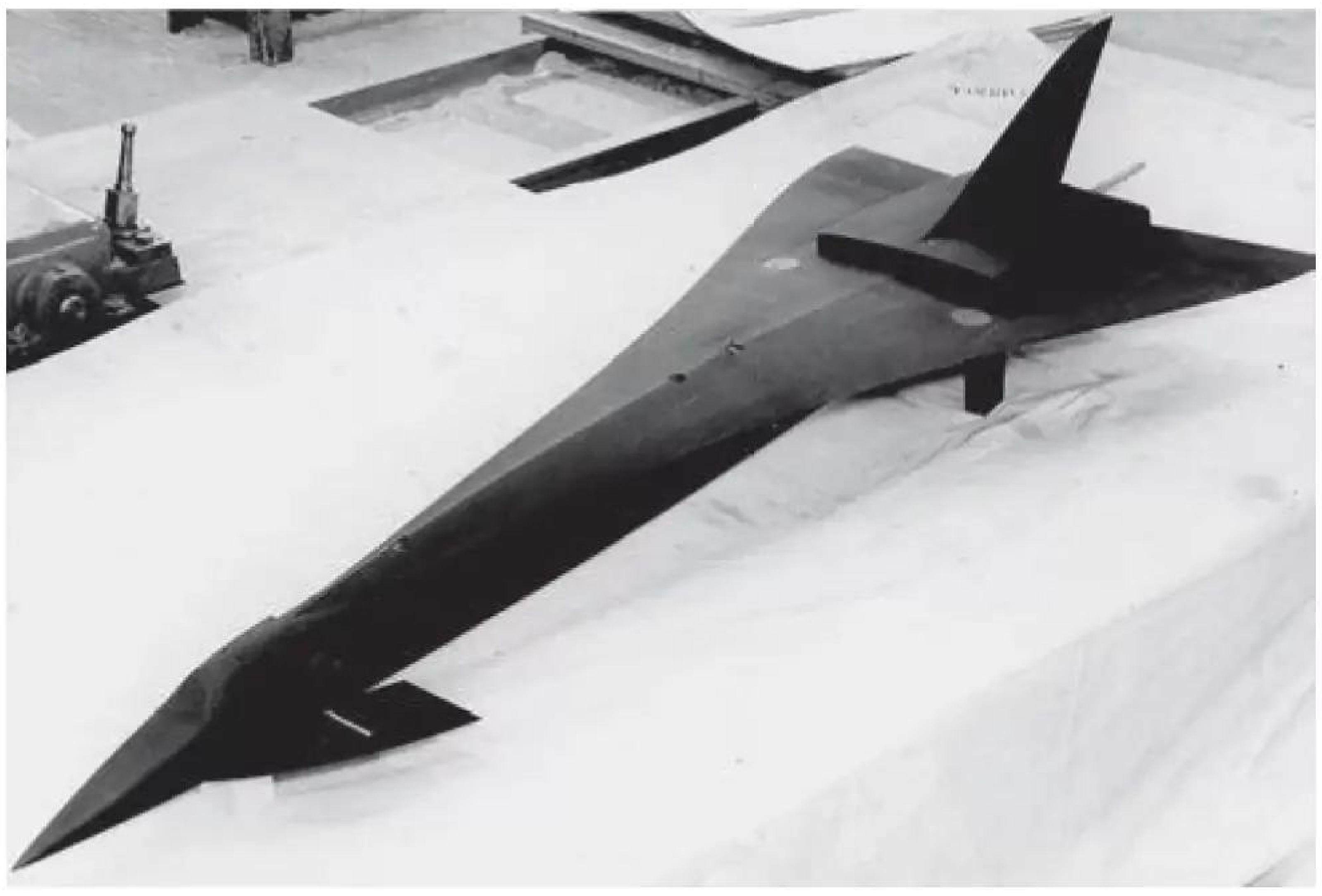
In fact the SST design effort nationwide seemed to grow after STAC released its proposals, as the following design studies and investigations made over several years illustrate. A factor which should also be borne in mind from this point onwards was the Government backed merger in 1960 of most of the country's individual aircraft manufacturers into two main concerns – the British Aircraft Corporation (BAC) which included Bristol, English Electric and Vickers, and Hawker Siddeley Aviation (HSA) which absorbed, amongst others, Armstrong Whitworth, de Havilland and Hawker.

BRISTOL TYPE 198A

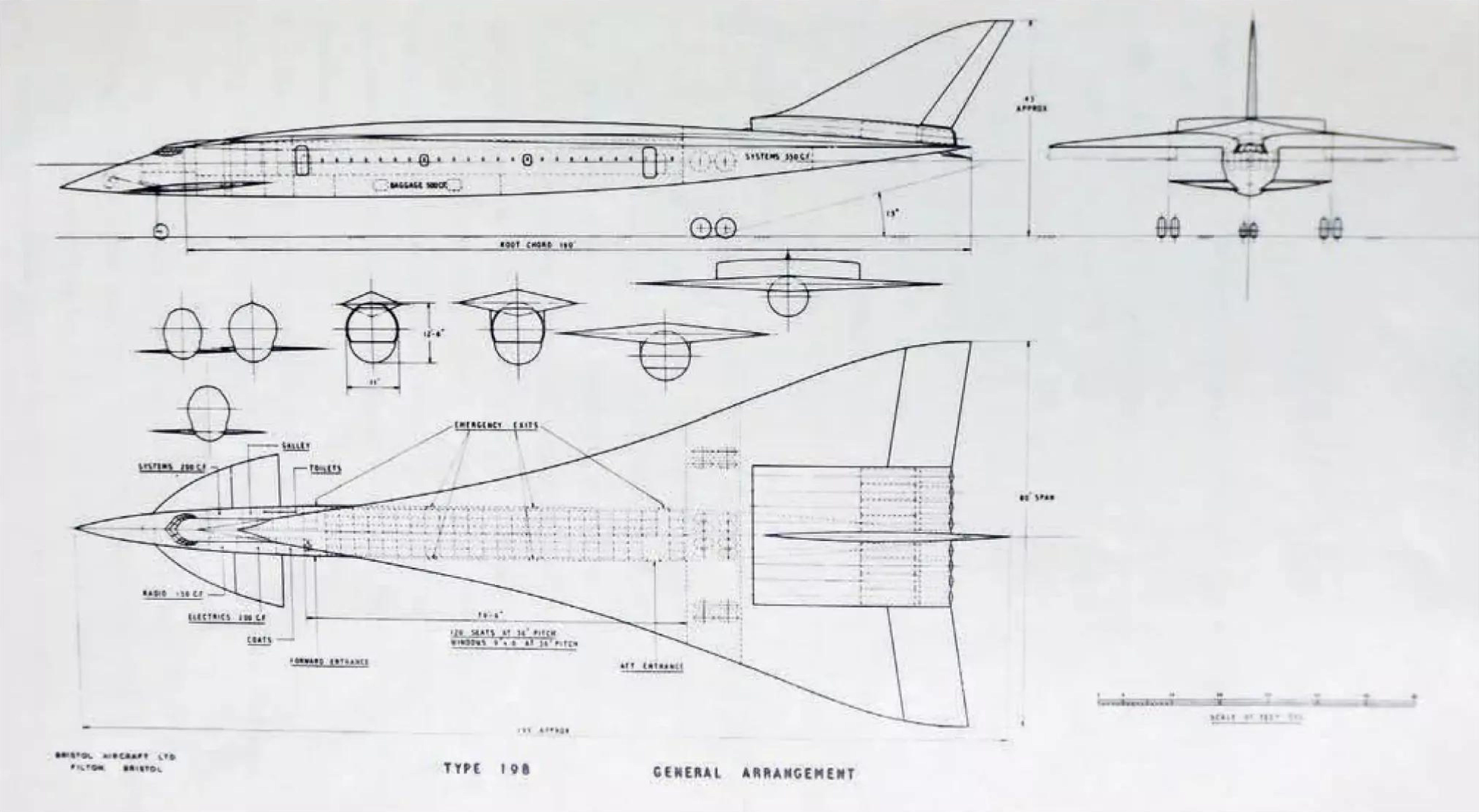
Bristol Aircraft Limited was awarded a contract by the MoS to compare the structural design of a light alloy aircraft for Mach 1.8 with that of a steel aircraft for Mach numbers around 3.0. In September 1959 Bristol also commenced a joint feasibility study with Hawker Siddeley Aviation, the purpose of which was to advise on the most suitable type of long-range supersonic aircraft, taking into account operating economics, timescale and costs. As a first step, the work concentrated on a design to fly at the limiting speeds for conventional light alloys and to carry around 100 passengers or slightly more on BOAC's western routes to Tokyo.

This particular version of Bristol's SST from January 1960 was called the 198A and the brochure contained just an outline of the light alloy aircraft proposed for this duty, though the light alloy structure would be supplemented by titanium used in the construction of the engine bay (steel or titanium might also be used where necessary to achieve adequate stiffness, e.g. for leading edge members). The chosen Bristol Olympus 591/3 engine was a civil version of the Olympus B.Ol.22 under development for the Ministry of Aviation to power the new BAC TSR.2 supersonic strike aircraft.

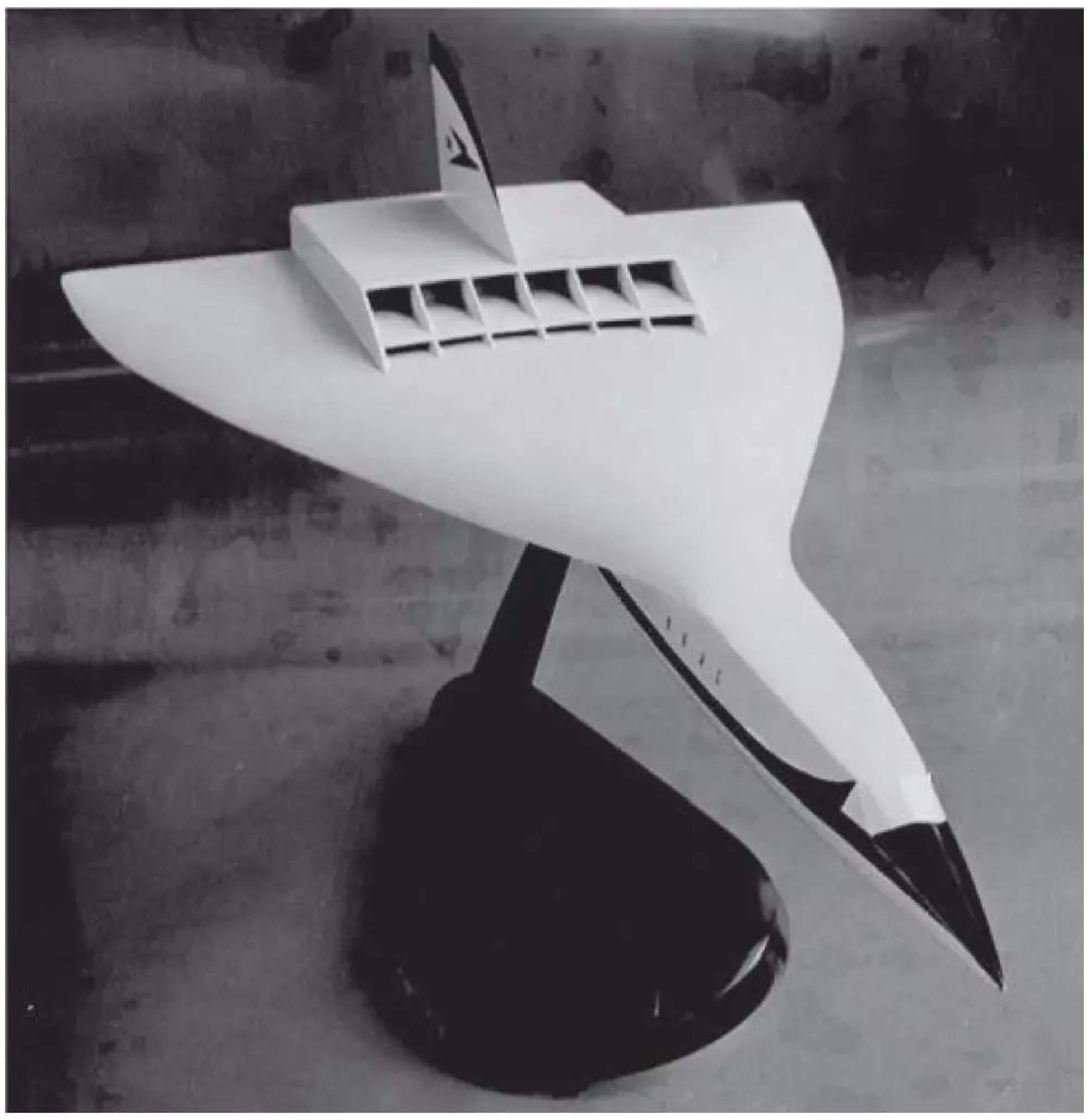
Following on from this specific brochure, by late 1960 the Bristol 198 had evolved and experienced changes to its planform and fuselage shape. Its span has been increased, the leading-edge sweep angle was reduced and the outer section of the trailing edge was swept 30°. These changes were intended to ease problems of balancing, to reduce the induced drag at all speeds and to improve low-speed stability and control characteristics.



Wind tunnel model of the Bristol 198 as the design appeared at 22 January 1959. BAE SYSTEMS *via Bristol Aero Collection*


SYSTEMS 350 C.F.
BAGGAGE 500 C.F.
ROOT CHORD 160'
13°
43' APPROX
12'-6"
EMERGENCY EXITS
GALLEY
SYSTEMS 200 C.F.
TOILETS
RADIO 150 C.F.
ELECTRICS 200 C.F.
COATS
FORWARD ENTRANCE
120 SEATS AT 34" PITCH
AFT ENTRANCE
80' SPAN
BRISTOL AIRCRAFT LTD
FILTON BRISTOL
TYPE 198
GENERAL ARRANGEMENT

This canard design had a span of 80ft (24.38m) and could carry 120 passengers. *National Archives*



Manufacturer's model of the Bristol 198 representing how the project looked on 18 September 1959. *BAE SYSTEMS via Bristol Aero Collection*

BRISTOL TYPE 198 VTOL

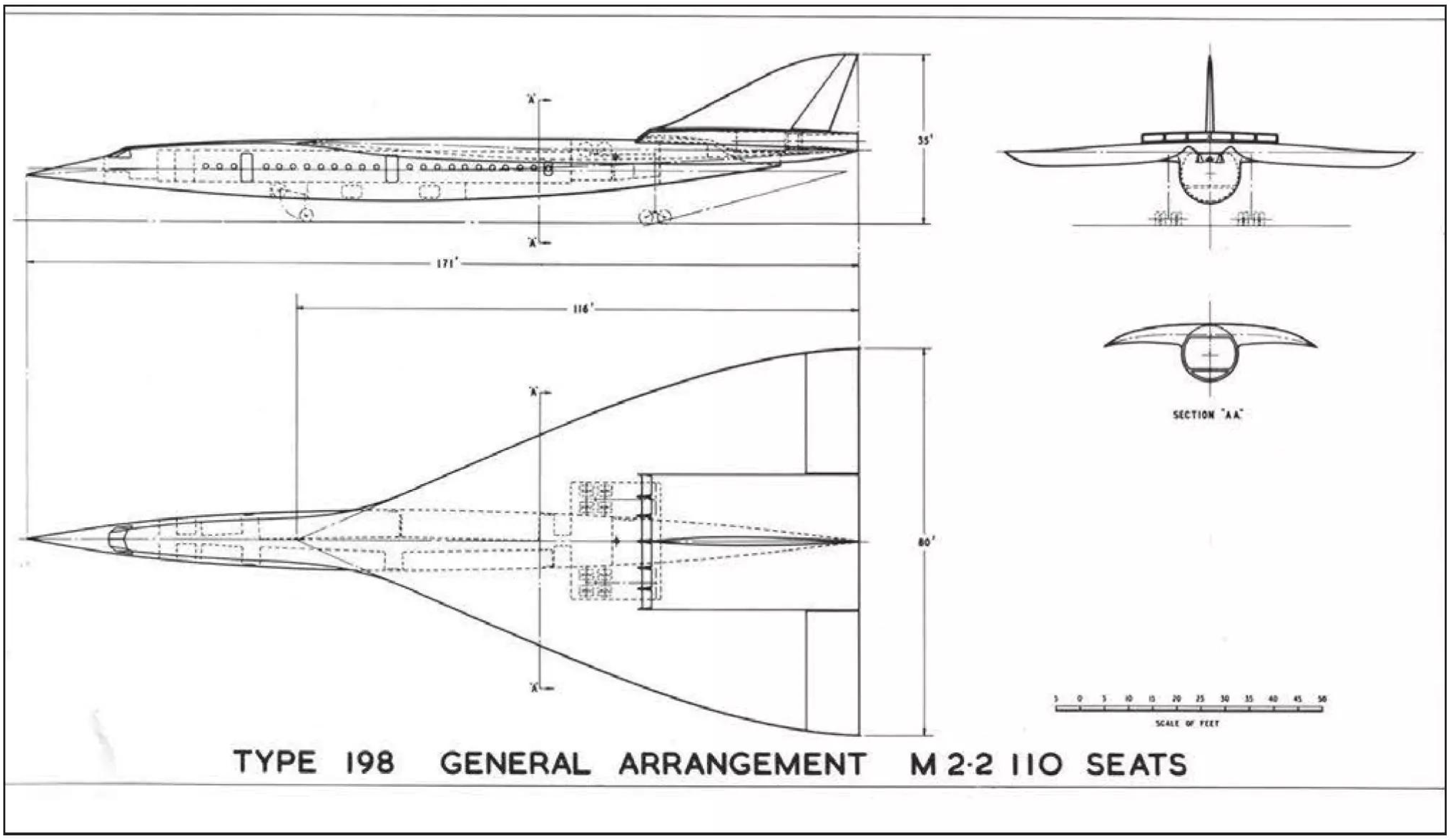
Bristol also drew a short and vertical take-off and landing (VTOL) version of its Type 198 with 30 lift engines in the wings, with a line of 15 down each side parallel to the sides of the fuselage. The type of lift engine selected was similar to the Bristol Siddeley BE.59/7 design and in addition there would be six propulsive units under the wing. The possibility of developing an SST with direct lifting engines had been proposed by Dr A.A. Griffith of Rolls-Royce. The basic arguments were that such an aircraft could have an aerodynamic design optimised for cruising and not compromised by take-off and landing considerations. In addition, the undercarriage could be simplified or eliminated if suitable landing pads could be devised.

In order to investigate these claims two variants of a Mach 2.2 design had been considered. One was related to STOVL (short take-off and vertical landing) operations and the other to VTOL operations and both were intended to operate over the some routes as conventional aircraft, i.e. to carry 122 passengers non-stop from London to New York. The VTOL type had an all-up-weight of 602,500lb (273,294kg), the STOVL version 442,150lb (200,559kg). The drawing shown is dated 3 June 1960.

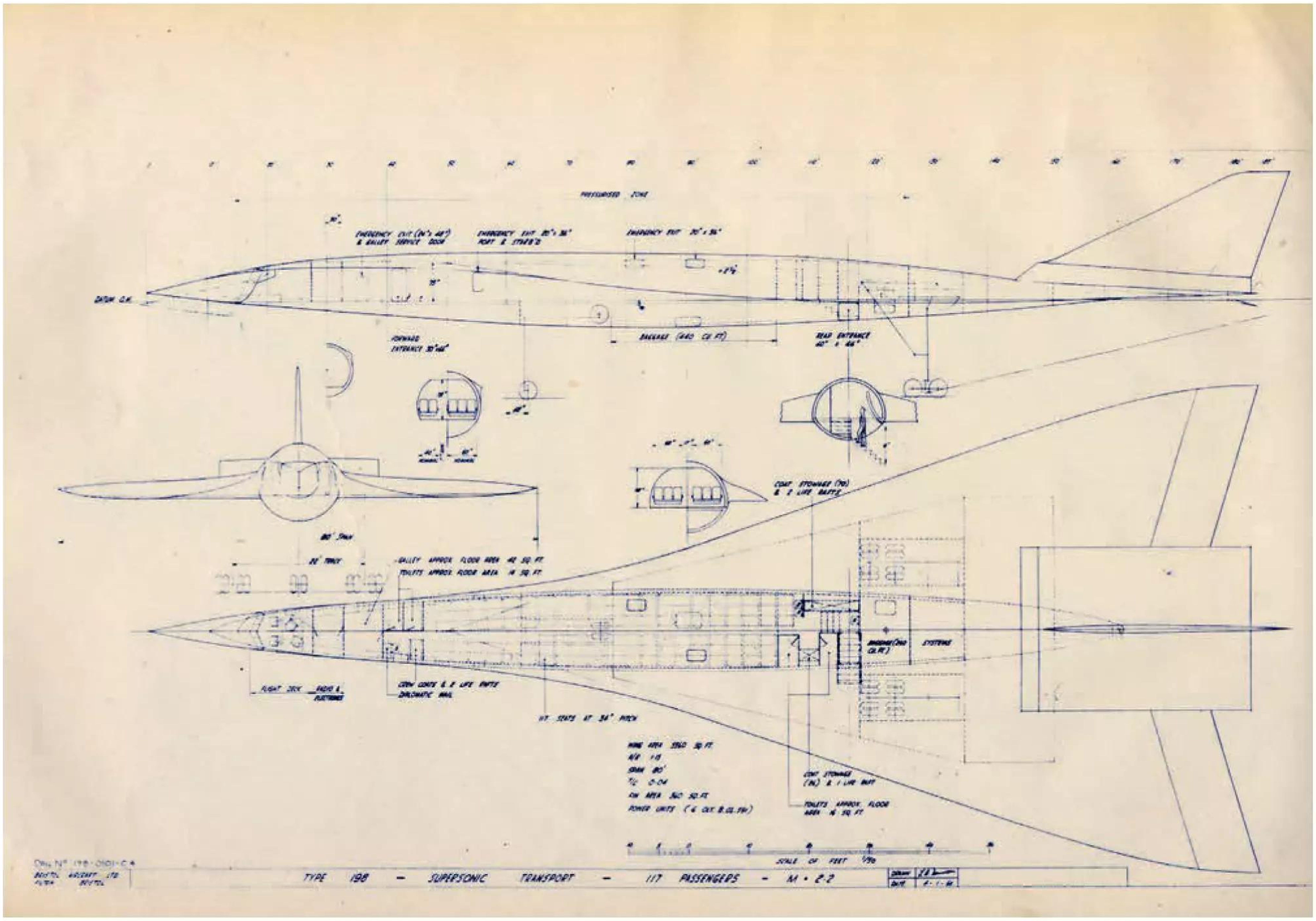
Bristol's SST research also included the Type 213 project of 1959, designed for speeds of Mach 3 – which meant a titanium and steel airframe. However, it was discovered that for a transatlantic crossing this aircraft would reduce journey time by only 10% over slower types, a figure which could not justify the 213's development and manufacturing costs.

BRISTOL TYPE 198

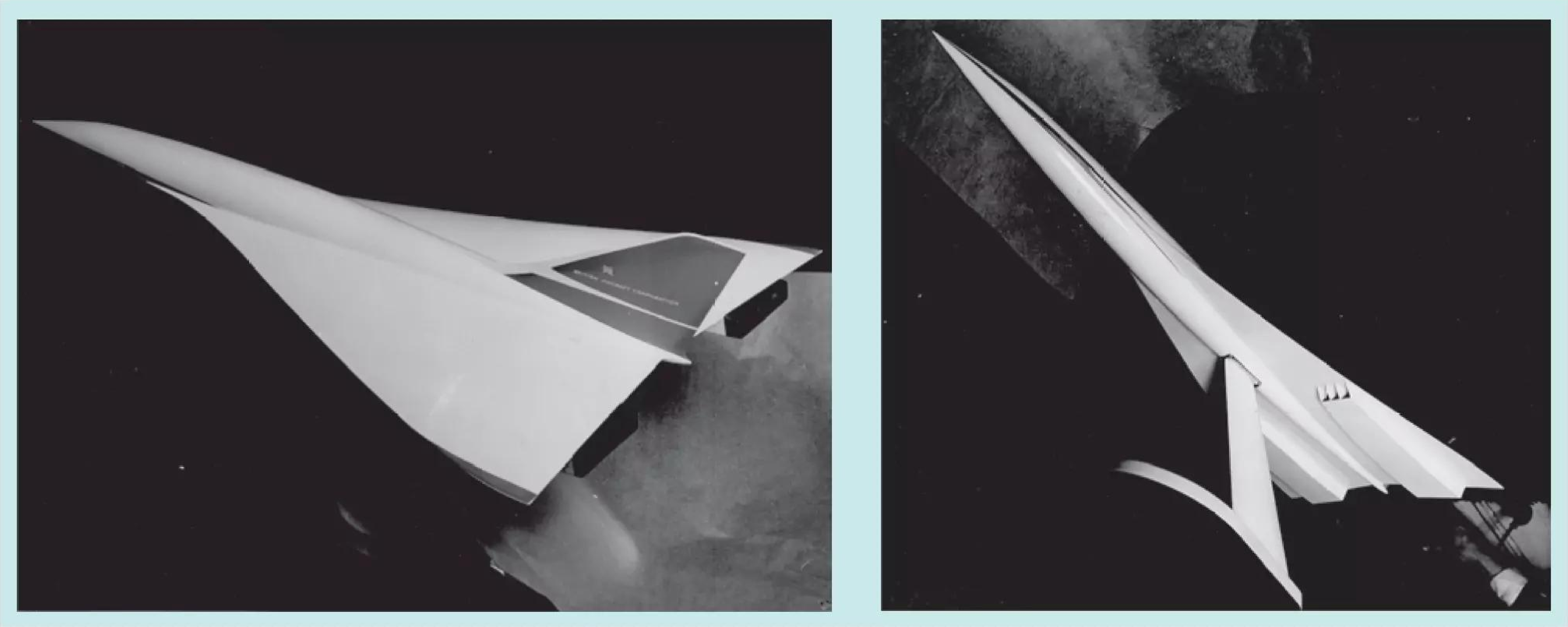
By the time the next Type 198 brochure and report were issued from BAC Bristol in August 1961 the design, based upon a slender delta wing, was beginning to mature. Experimental evidence had been available for some time which had demonstrated that the ideal application of the


TYPE 198 GENERAL ARRANGEMENT M 2·2 110 SEATS
171'
116'
35'
80'
'A'
SECTION 'AA'
SCALE OF FEET

Bristol Type 198 3-view at September 1959. Span 80ft (24.38m), length 171ft (52.12m), 110 seats. *Martyn Chorlton*

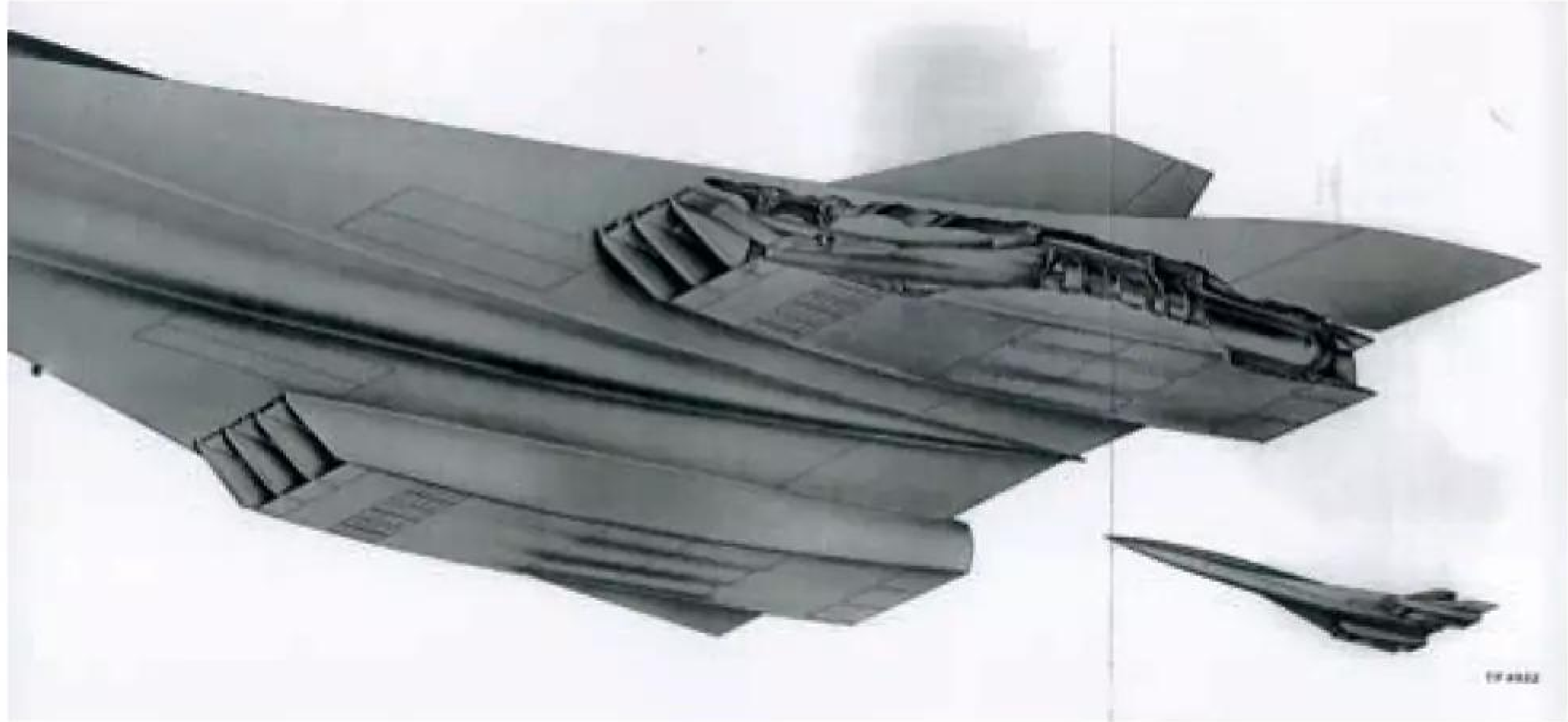

PRESSURISED ZONE
TYPE 198 - SUPERSONIC TRANSPORT - 117 PASSENGERS - M · 2·2
SCALE OF FEET
80' SPAN
WING AREA 3560 SQ FT
SPAN 80'
FIN AREA 360 SQ FT

Bristol Type 198A (4.1.60). *North West Heritage Group*

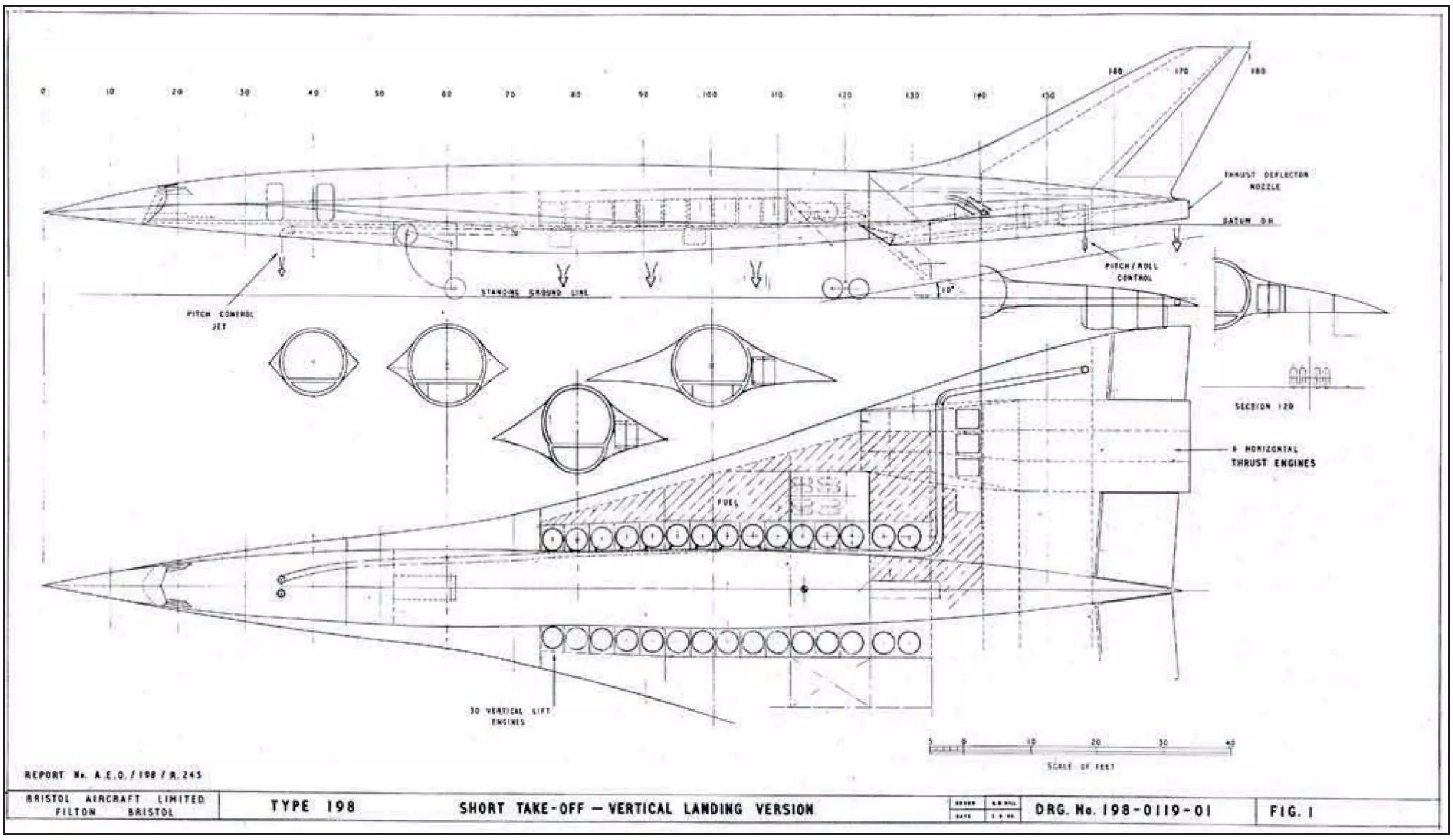


Photos dated 22 March 1960 showing another manufacturer's model of the Bristol 198A. The engines have now been moved to beneath the wings. *BAE SYSTEMS via Bristol Aero Collection*

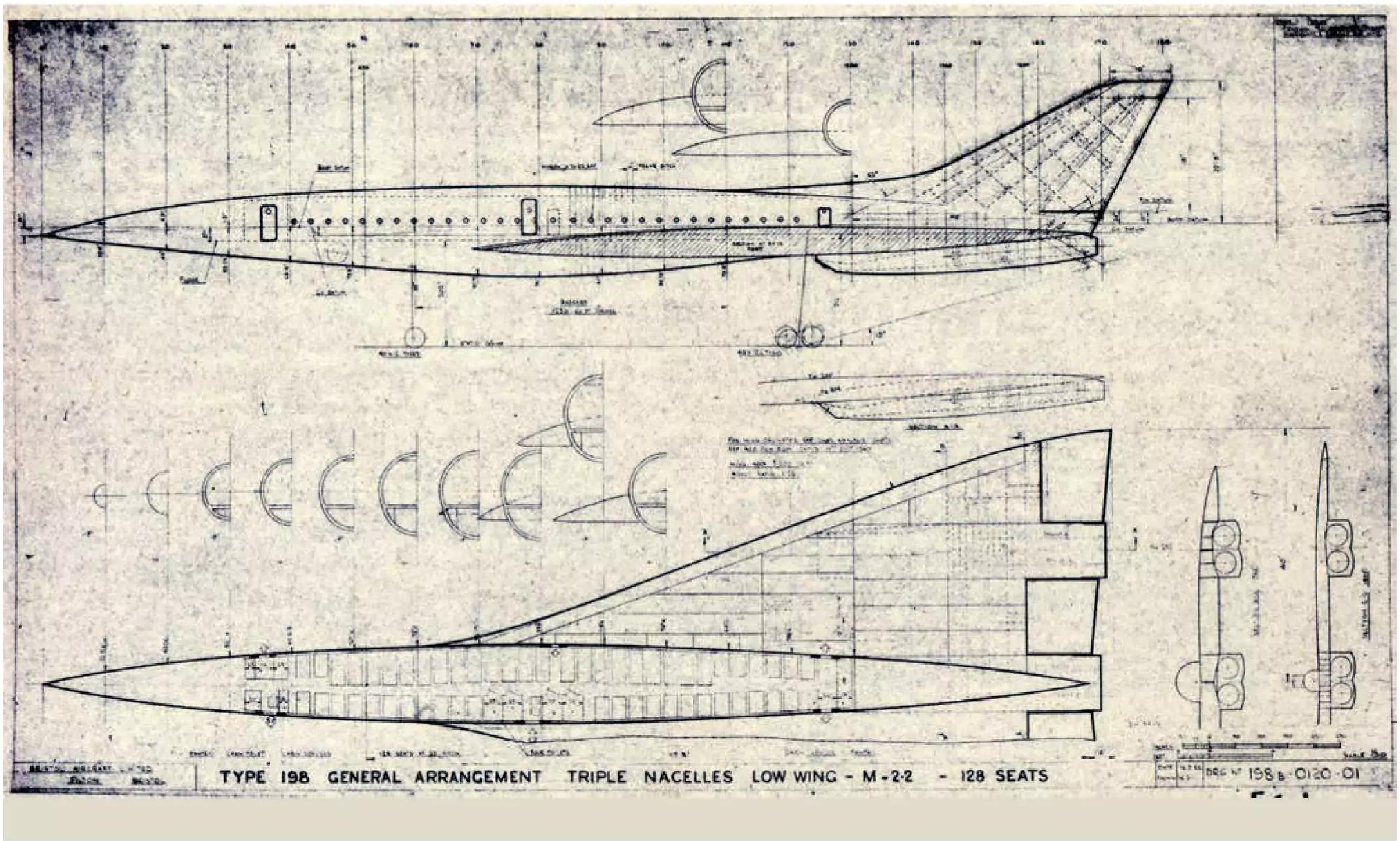
aerodynamic principles involved, in which the passenger accommodation was enclosed wholly within the wing contours, yielded good supersonic efficiency in terms of the lift/drag ratio. In the practical application to a design of the desired size, however, it was found that the wing could not be sufficiently deep to house the passengers and that a recognisable fuselage had to exist. Further, since even on a long-range journey about 30% of the fuel carried was burnt at subsonic speed, the wing design must be a compromise between the subsonic and supersonic requirements.



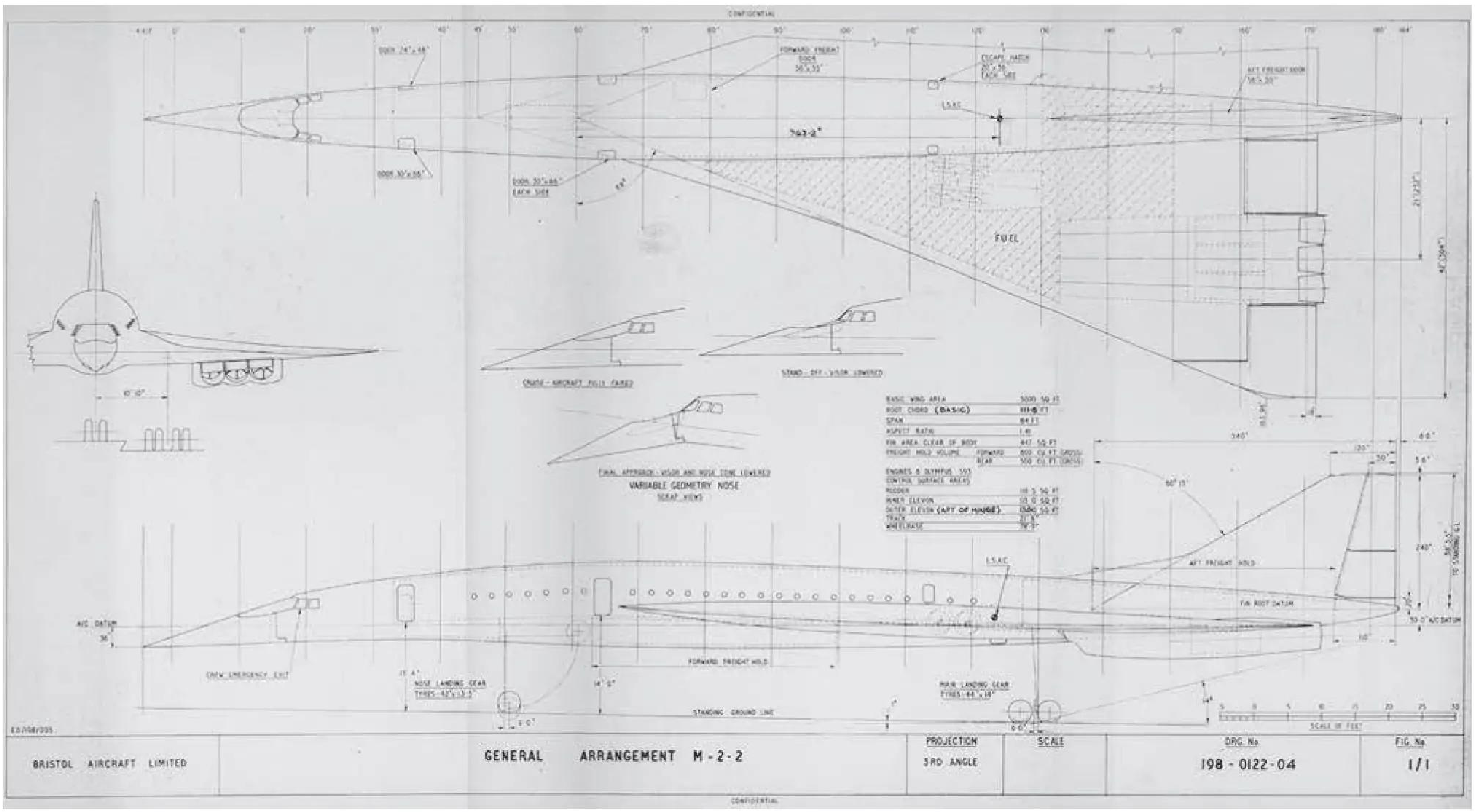
Brochure drawing showing Bristol 198A powerplant detail.


THRUST DEFLECTOR NOZZLE
DATUM OH
PITCH / ROLL CONTROL
STANDING GROUND LINE
PITCH CONTROL JET
10°
SECTION 120
8 HORIZONTAL THRUST ENGINES
FUEL
30 VERTICAL LIFT ENGINES
SCALE OF FEET
REPORT No. A.E.O. / 198 / R. 245
BRISTOL AIRCRAFT LIMITED FILTON BRISTOL
TYPE 198
SHORT TAKE-OFF — VERTICAL LANDING VERSION
DRG. No. 198-0119-01
FIG. I

The extraordinary concept for a VTOL version of the Bristol Type 198 (3.6.60). *BAE SYSTEMS via Bristol Aero Collection*


BRISTOL AIRCRAFT LIMITED FILTON BRISTOL
TYPE 198 GENERAL ARRANGEMENT TRIPLE NACELLES LOW WING - M-2.2 - 128 SEATS
DRG No 198B-0120-01

Bristol 198 at September 1960. Note engines split into three pairs. *North West Heritage Group*


CONFIDENTIAL
FUEL
L.S.A.C.
CRUISE - AIRCRAFT FULLY FAIRED
STAND - OFF - VISOR LOWERED
FINAL APPROACH - VISOR AND NOSE CONE LOWERED
VARIABLE GEOMETRY NOSE
SCRAP VIEWS
BASIC WING AREA
ROOT CHORD (BASIC)
SPAN
ASPECT RATIO
FIN AREA CLEAR OF BODY
FREIGHT HOLD VOLUME FORWARD
REAR
ENGINES 6 OLYMPUS 593
CONTROL SURFACE AREAS
RUDDER
INNER ELEVON
OUTER ELEVON (AFT OF HINGE)
TRACK
WHEELBASE
A/C DATUM
CREW EMERGENCY EXIT
NOSE LANDING GEAR
FORWARD FREIGHT HOLD
STANDING GROUND LINE
MAIN LANDING GEAR
AFT FREIGHT HOLD
FIN ROOT DATUM
SCALE OF FEET
BRISTOL AIRCRAFT LIMITED
GENERAL ARRANGEMENT M-2-2
PROJECTION
3RD ANGLE
SCALE
DRG. No
198 - 0122-04
FIG. No
1/1

Bristol 198 at September 1961. The engines are now in two groups of three on what is the final known configuration of Bristol's large SST project. *Bristol Aero Collection*

Bristol Siddeley Engines and Rolls-Royce, had co-operated with the firm to determine the most suitable engine design, with the high pressure ratio, twin-spool turbojet Olympus 593/3 and RB.171-4 bypass turbojet with front fan being selected. In both cases, the engine met the take-off and cruise thrust demands without reheat, but sonic boom considerations during the transition from subsonic to supersonic speed required that a moderate degree of reheat must be used in this phase.

At this stage, the 198 was basically of aluminium alloy construction, designed for Mach 2.2 cruise, and capable of non-stop transatlantic operation. It was a delta-winged monoplane with one vertical tail surface, a discrete fuselage and tricycle landing gear. Titanium alloys would be used in the engine nacelles with steel and nickel alloys also used where additional strength and stiffness were needed. The flight deck and passenger accommodation as conventional as was practicable in regard to the supersonic capability of the aircraft. The nose of the fuselage forward of the flight deck was variable so as to present a smooth contour, but in this position it gave no direct forward vision in supersonic cruise and needed to be lowered at low speeds to expose the full windscreen. Indirect vision was to be provided in cruise by optical means.

The normal minimum flight crew would consist of a 1st pilot, 2nd pilot, 3rd pilot and flight engineer. In the standard arrangement, accommodation was provided for 136 economy class passengers, but 146 could be accommodated with different seating. There were two cargo holds: 600cu ft (16.98cu m) capacity up front and 500cu ft (14.15cu m) to the rear. Provision was to be made for carrying 8,000lb (3,629kg) of mail or freight and fuel load was 186,380lb (84,542kg). A range of quoted dive speeds included Mach 1.10 from 17,500-33,500ft (5,334-10,211m) and Mach 2.35 above 51,000ft (15,545m).

DE HAVILLAND DH.130

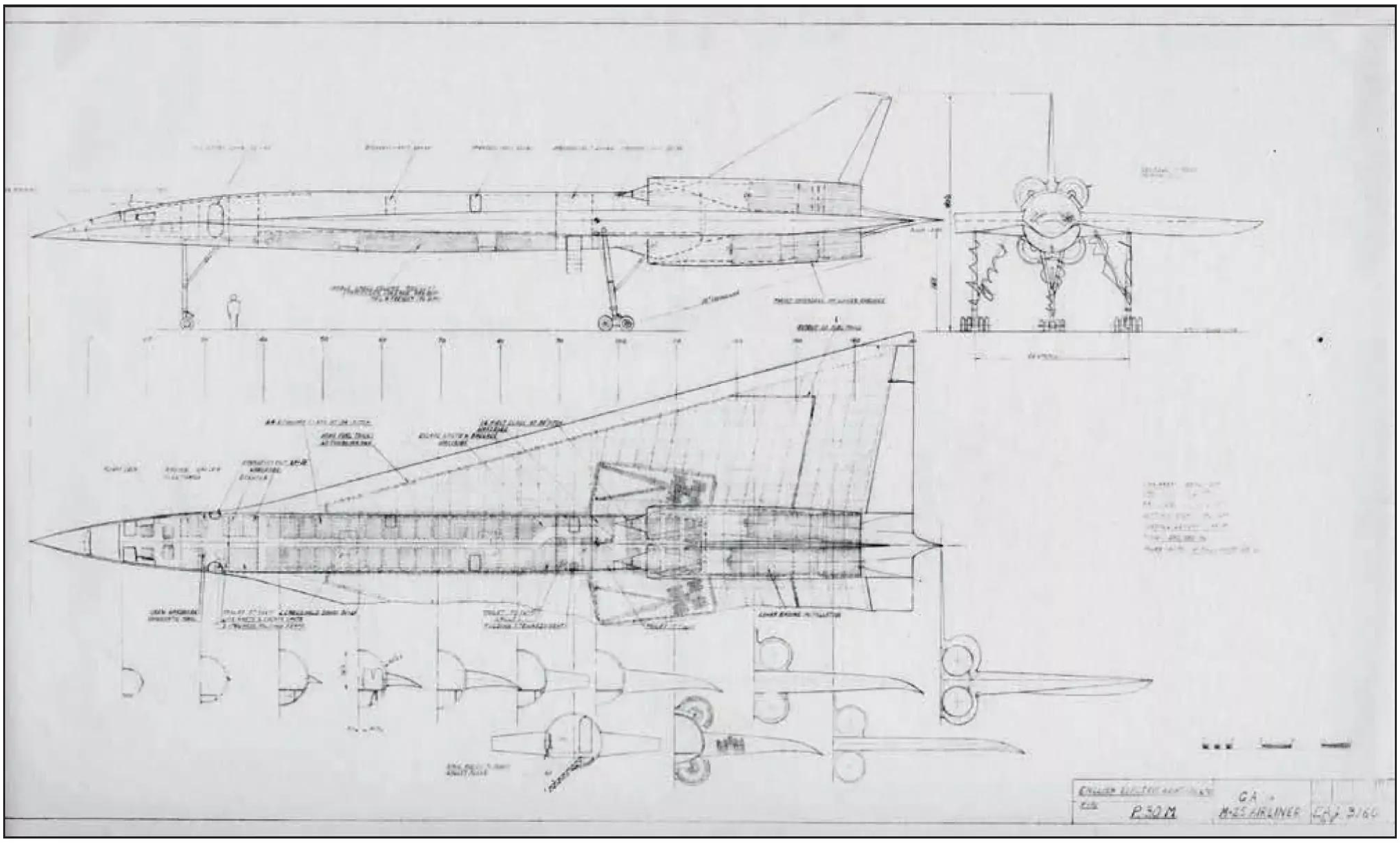
The variable geometry DH.130 project was one of several produced by this firm for STAC. It had three RB.178 engines, one in the fin with the others beneath the wings. Estimated range was 2,350nm (4,355km). The Advanced Projects Group at Kingston eventually developed this design into the HS.1101 below, while another de Havilland study looked at a slender delta layout capable of Mach 1.8.

ENGLISH ELECTRIC P.30

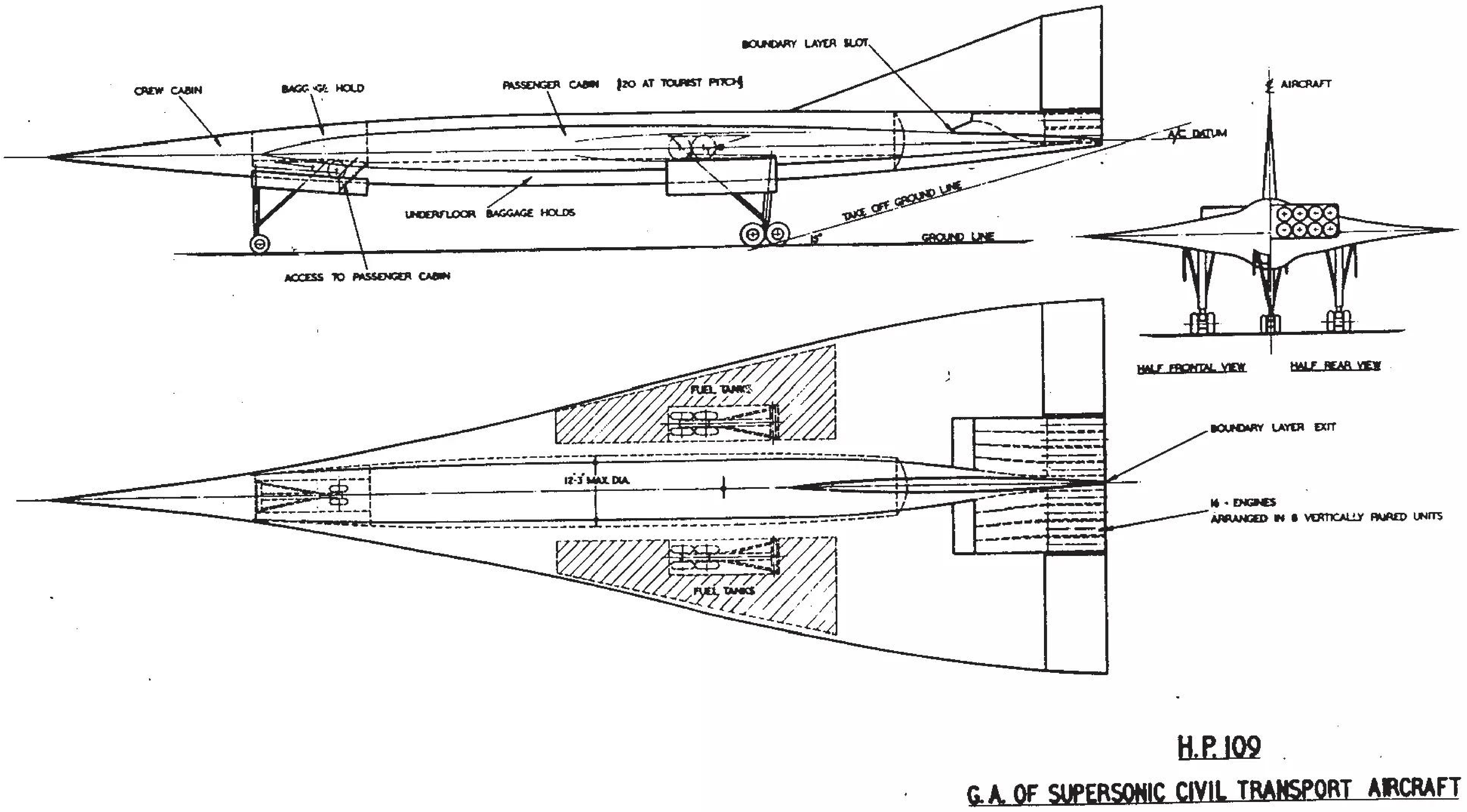
From about May 1959 to December 1960 English Electric produced some 30 drawings relating to variants of its P.30 SST project (including designations P.30A to R). The version shown here, one of the more detailed drawings, is the P.30M slim delta design with four RB.160 engines in the rear fuselage stacked in pairs (the RB.160 was a Rolls-Royce project from 1959 for a new engine designed specifically for supersonic transports). P.30M's undercarriage had eight-wheel main gear bogies and there were four wheels on the nose leg (though on the nose angle view the long undercarriage legs have been crossed out which suggests that these may have proved unsatisfactory). A lower mid-fuselage bay offered 500cu ft (14.15cu m) of useable cargo volume.

HANDLEY PAGE HP.128

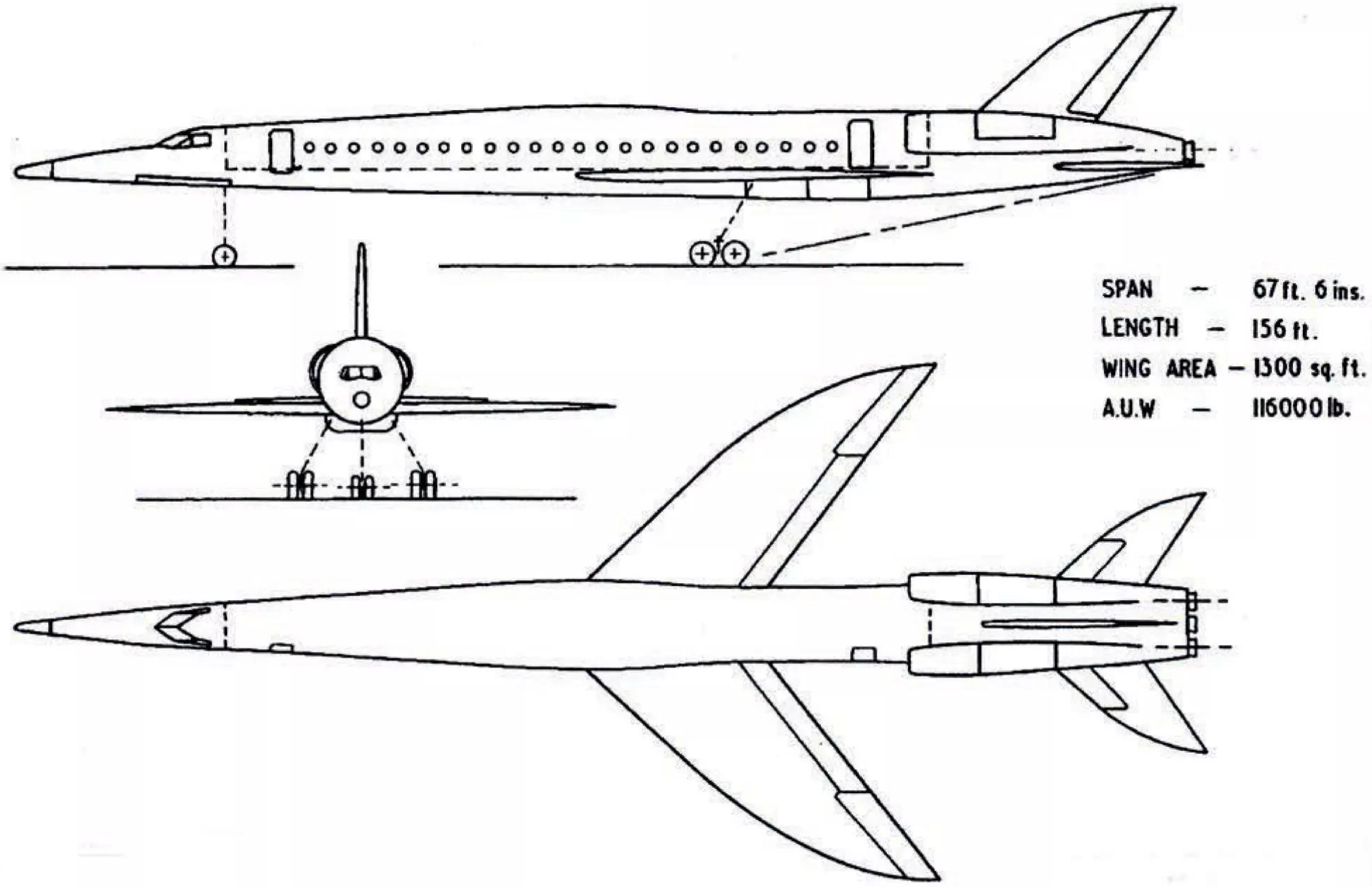
Handley Page appears to have begun its own SST studies in around 1957 with the HP.109, a Mach 1.8 project that looked



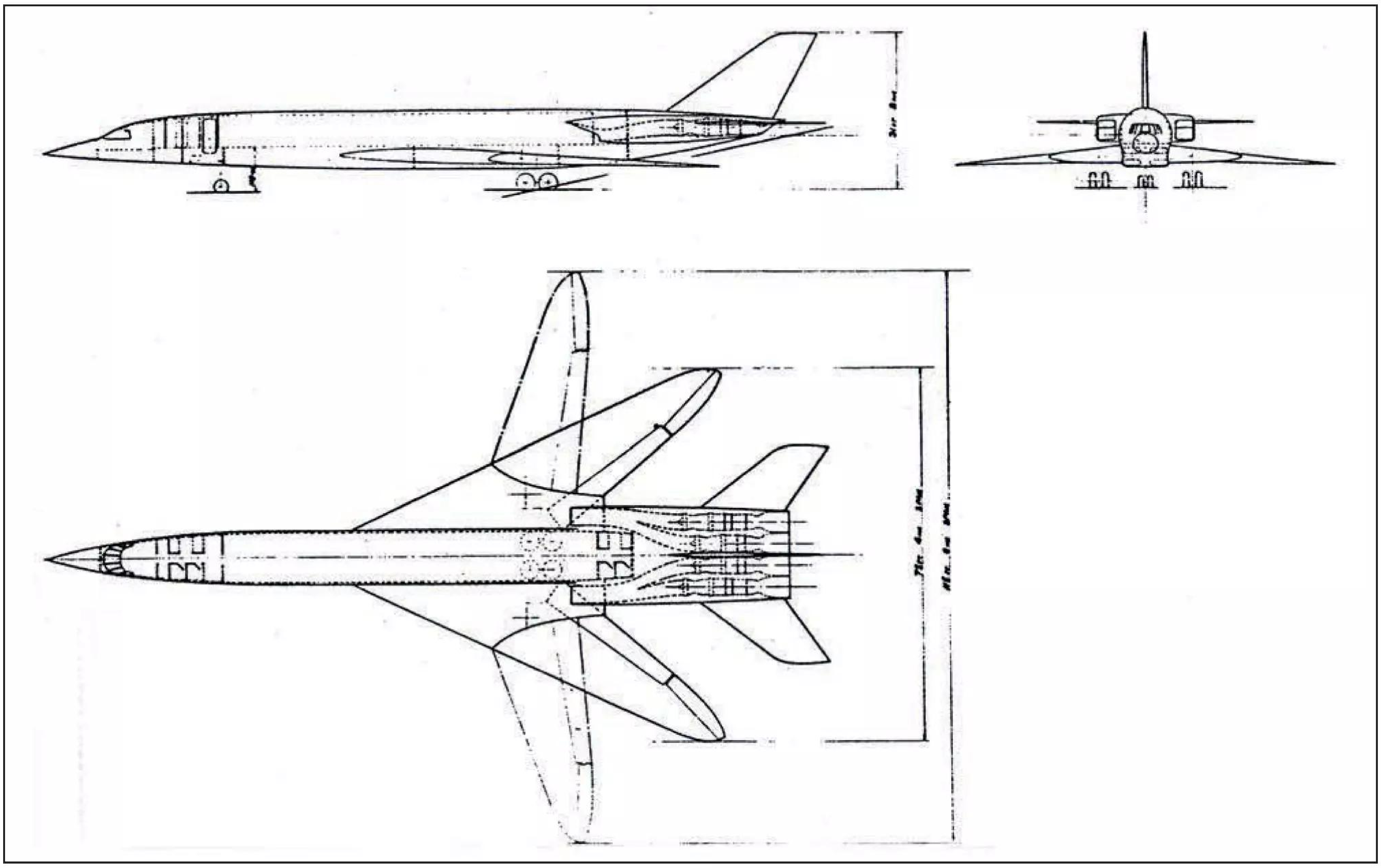
English Electric P.30M (c1960). *North West Heritage Group*


BOUNDARY LAYER SLOT
CREW CABIN
BAGGAGE HOLD
PASSENGER CABIN (20 AT TOURIST PITCH)
£ AIRCRAFT
A/C DATUM
TAKE OFF GROUND LINE
UNDERFLOOR BAGGAGE HOLDS
15°
GROUND LINE
ACCESS TO PASSENGER CABIN
HALF FRONTAL VIEW
HALF REAR VIEW
FUEL TANKS
BOUNDARY LAYER EXIT
12'-3" MAX DIA
16 - ENGINES
ARRANGED IN 8 VERTICALLY PAIRED UNITS
FUEL TANKS
H.P. 109
G.A. OF SUPERSONIC CIVIL TRANSPORT AIRCRAFT

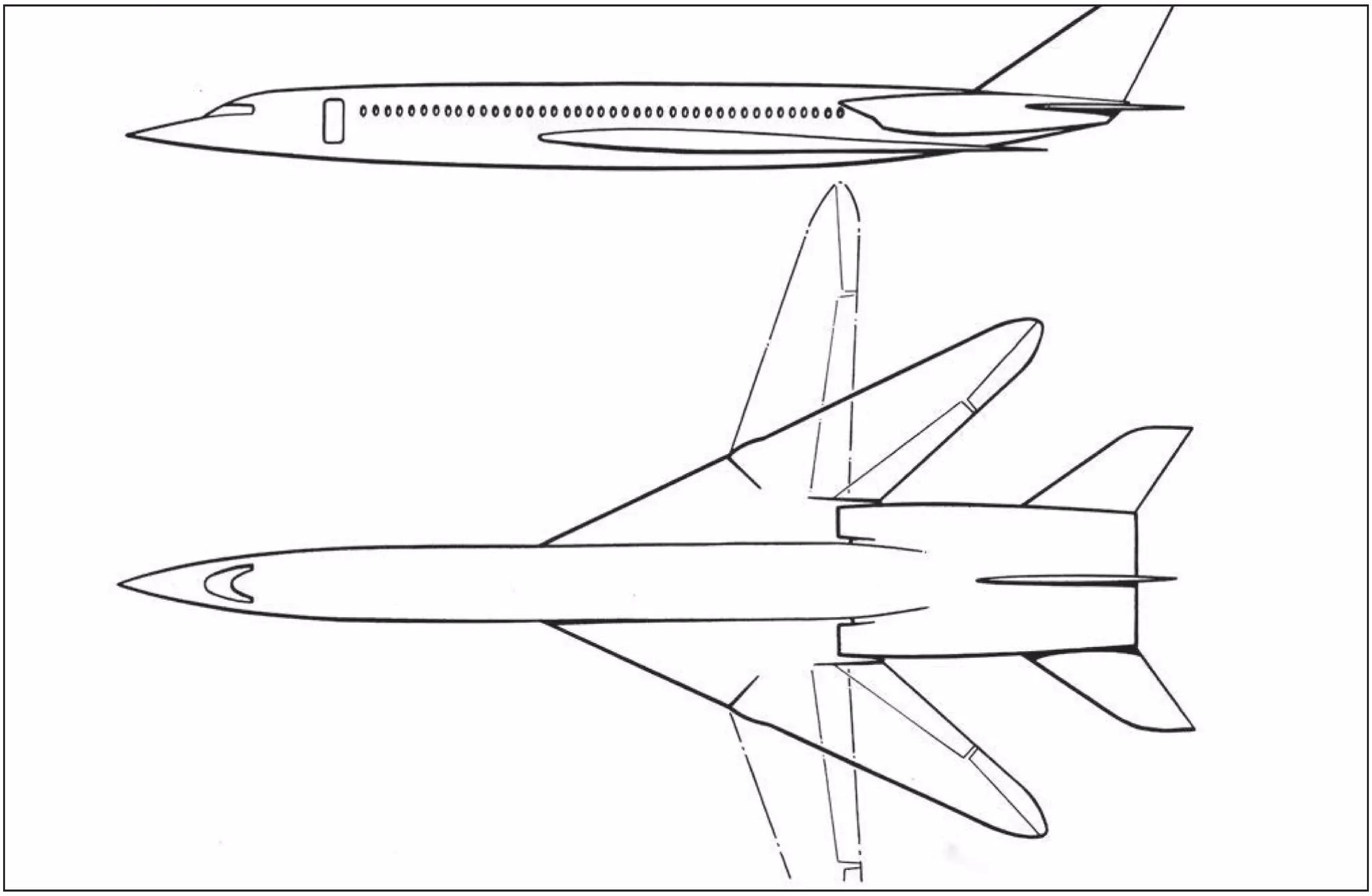
This version of Handley Page's HP.109 project used a tricycle undercarriage, its fuel was housed in wing tanks and a battery of 16 engines was arranged in eight vertically paired units (1957). *National Archives via Richard Payne*


SPAN – 67 ft. 6 ins.
LENGTH – 156 ft.
WING AREA – 1300 sq. ft.
A.U.W – 116000 lb.

Handley Page HP.128 (4.6.64). *National Archives DSIR 23/31806*



Vickers Civil Transport Study (29.11.61). *National Archives DSIR 23/29195*



A Vickers-Supermarine Type 586/587 drawing. The Types 586 and 587 designations covered airliners designed for Mach 2+ speeds.

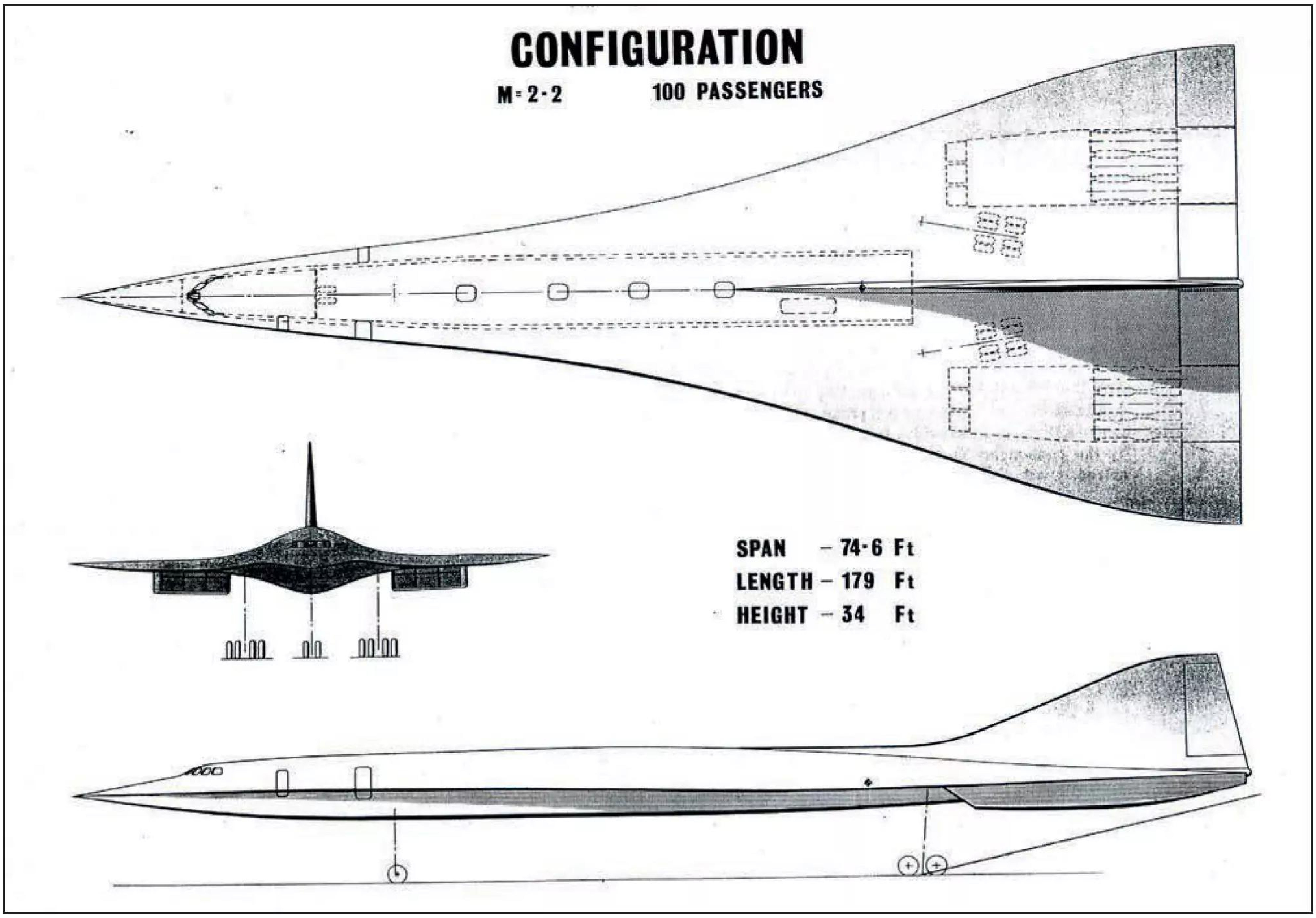
at several versions of slender delta wings, both thick and thin. The HP.110 was a further project designed for medium ranges at up to Mach 1.3. And later in 1960 Handley Page conducted research into laminar flow for a Mach 2.2 design in collaboration with Hawker Siddeley. But the most well-known SST design from this company was the short range HP.128. The original design was shown in model form at the September 1962 Farnborough Show, and at that stage it was intended to be "just-supersonic" so as to avoid any "devastation" on the ground brought about by the effect of sonic booms.

A brochure from June 1964 described an updated design. The manufacturer had decided to investigate the possibility short range type cruising at Mach 1.1-1.2. This was chosen as it would be possible to cruise at up to 1.15 in the stratosphere without producing sonic bangs on the ground. Most of the work had been carried out about two years previously but since then this aircraft been somewhat modified. The earlier version's all-up-weight was 90,000lb (40,824kg) with a gross wing area of 1,210ft2 (112.53m2) and fuselage length of 131ft (39.93m), and the calculations used for that design had been taken as the basis for this new report. The aeroplane previously studied in detail had comprised an area-ruled fuselage with highly swept quasi-subsonic wings, optimised for around 90 passengers, but the size of this aircraft had been increased to accommodate 125 passengers. It was emphasized that the effort put into this investigation was limited and that the results given were preliminary only.

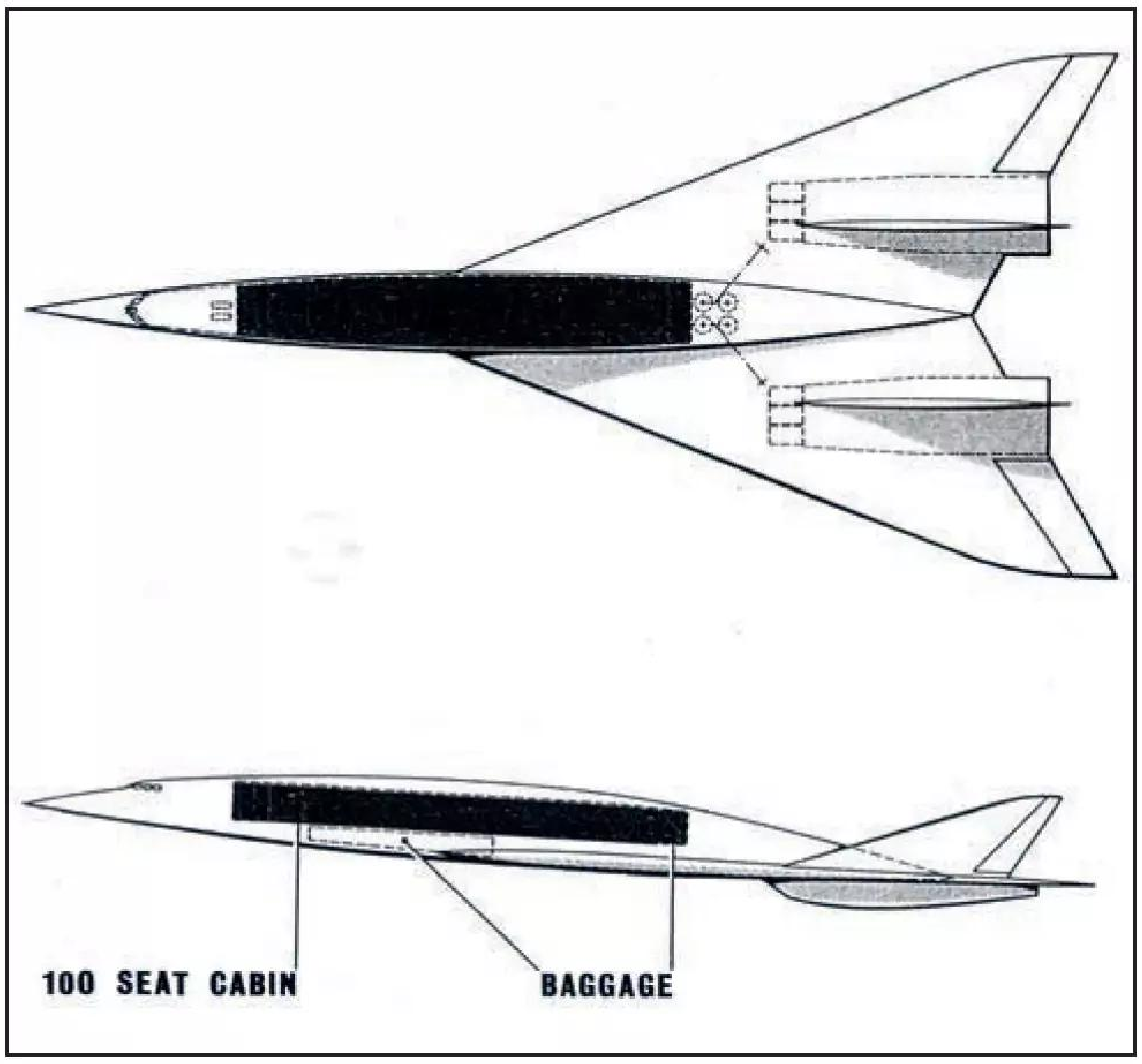
The HP.128's wing was provided with blown (or sucked) trailing-edge flaps and with nose flaps having suction at the knuckle when deflected. Wing sweep angle was 45° at the quarter chord line. The fuselage and tail unit were of conventional aluminium construction and a prominently waisted fuselage signified area-ruling.

Three Rolls-Royce Spey type engines, scaled up by a factor of 1.45, were positioned in the rear fuselage to save nacelle drag and reduce fuselage wave drag. Unstick speed at all-up-weight was 177 knots (328km/h), the journey length was taken as 500 statute miles (805km) and maximum fuel load was 17,980lb (8,156kg).

A brief study for a comparative subsonic aircraft showed a wing swept 30° at quarter chord, the same 125 seats, three engines but giving a combined thrust of only 26,000lb (15.6kN), and cruise speed of 441 knots (817km/h) at 36,000ft (10,973m). Span was 90ft 8.5in (27.65m), wing area 1,030sqft (95.79sqm) and all-up weight 90,660lb (41,123kg) when carrying its full 14,500lb (6,577kg) load of fuel. The



Hawker Siddeley Type 1000 (1961). *National Archives via Richard Payne*



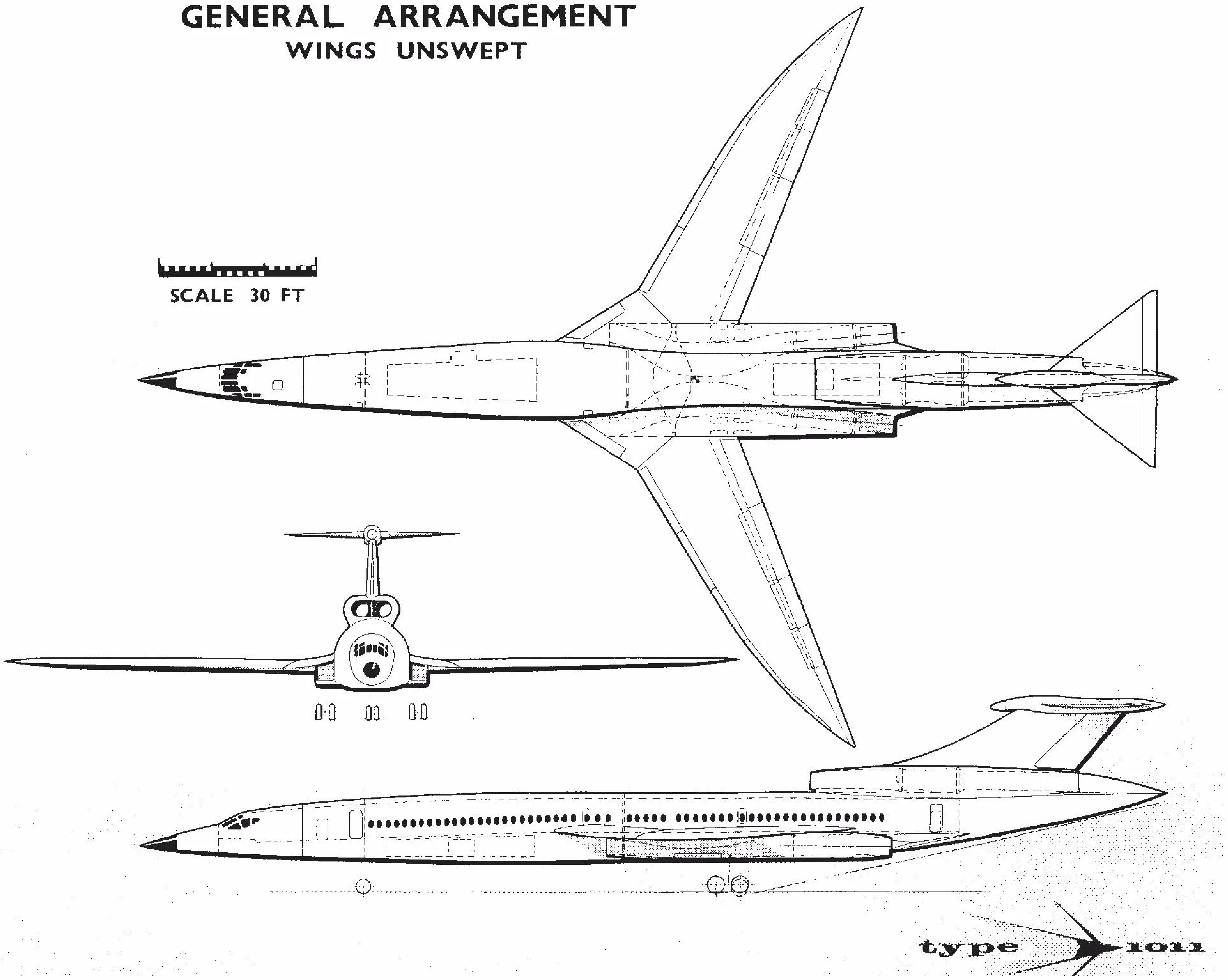
Just to illustrate the level of research undertaken into SST configurations at this time, the HS 1000 brochure included this further arrangement for a Mach 2.7 aircraft. *National Archives via Richard Payne*

results showed that the HP.128 compared well with existing aeroplane types of a similar size but was about 15% more expensive than the corresponding subsonic type. This appeared to indicate that there was a significant economic penalty in attempting to attain supersonic cruise speeds for short ranges. Handley Page would go into liquidation in 1970.

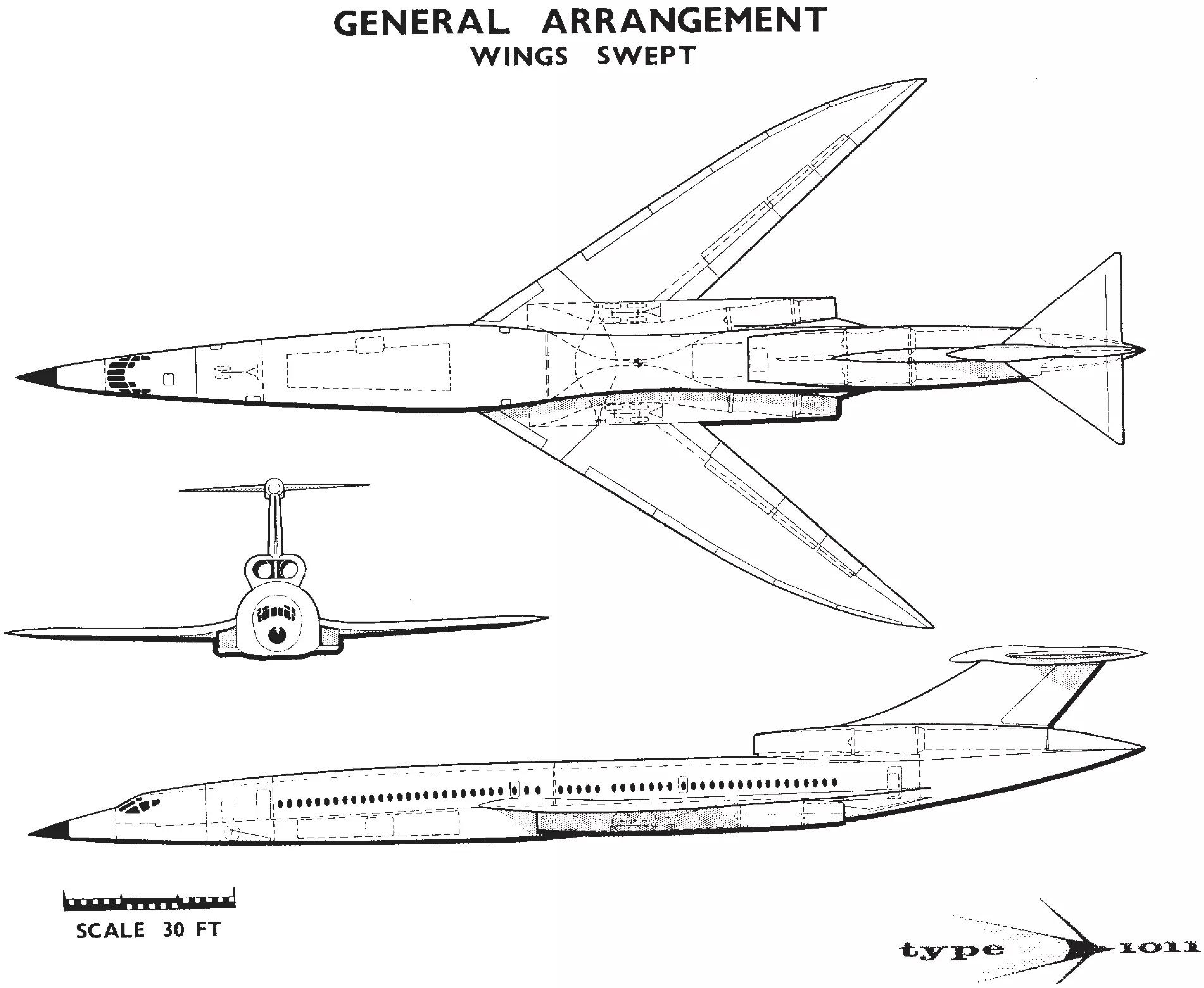
VICKERS CIVIL TRANSPORT STUDY (TYPES 586 AND 587)

Vickers-Armstrongs (BAC) completed a wide-ranging 'Variable Sweep and the Supersonic Transport' report on 29 November 1961 covering swing wings and both military and civilian high-performance types. In terms of performance and cost, the variable geometry (VG) sweep wing aircraft was shown to be as good as or better for a civil transport than the best fixed wing configurations. It was also said to have better take-off and landing performance as well as lower noise levels on the ground.

Vickers had developed a configuration in which the wing, pivoted near its root, swept forward for the low speeds involved in landing, take-off, subsonic climb and



Hawker Siddeley Type 1011 with wings 'unswept' (6.61). *National Aerospace Library*



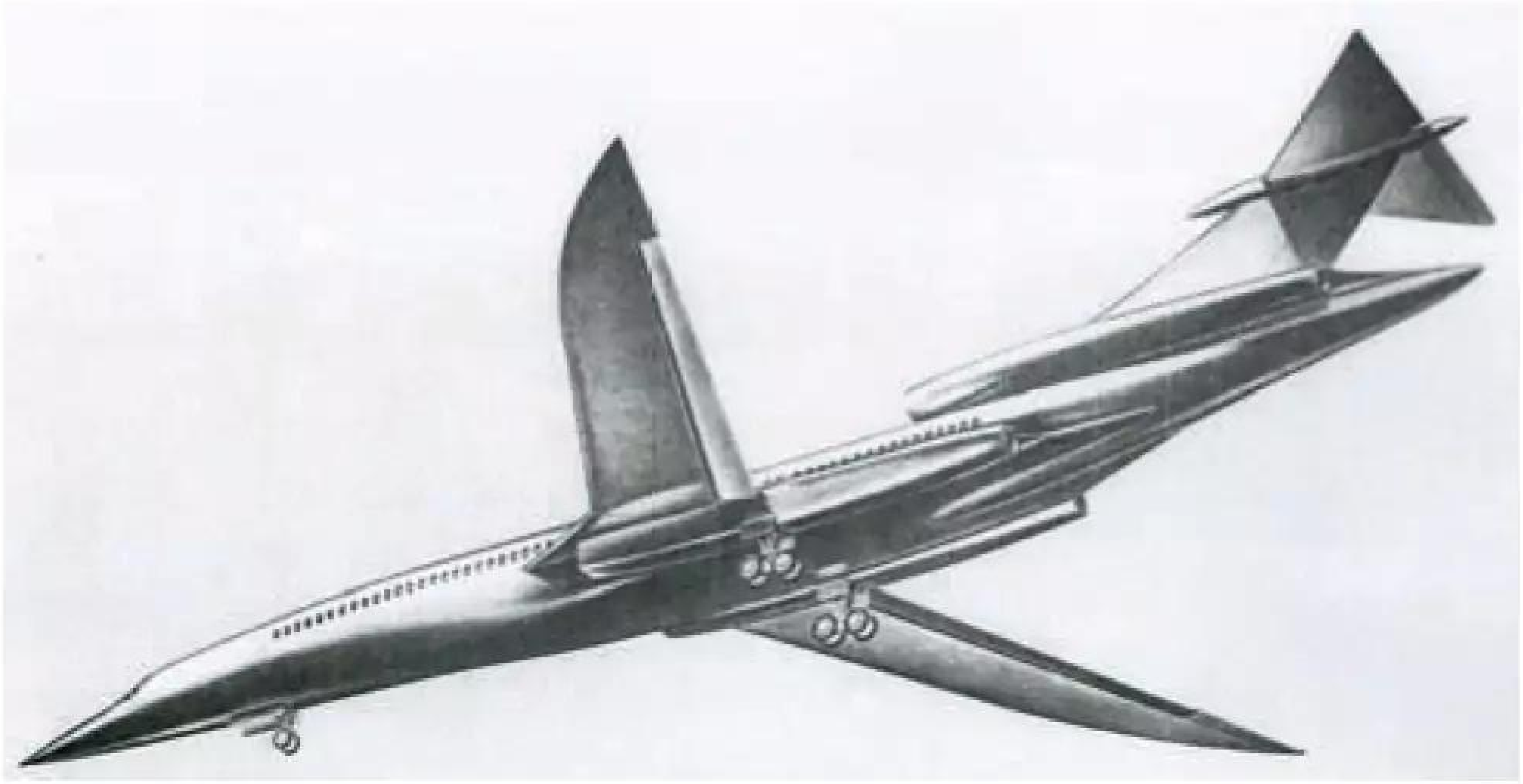
Hawker Siddeley Type 1011 with wings fully swept (6.61). *National Aerospace Library*

stacking prior to landing. For transonic flight conditions, it would move rearwards to assume a 50-65° angle of sweep, with a considerably reduced span and aspect ratio. At higher supersonic Mach numbers, the wing sweep could be increased further, reducing wave drag by maintaining a subsonic leading edge, or to reduce trim drag, or both.

A separate research report dealing with the SST had expressed concern with, amongst other things, the slender delta's high approach speeds and handling characteristics and the Air Traffic Control problems associated with mixed traffic patterns which included supersonic transport aircraft with higher than usual stacking and approach speeds.

HSA TYPE 1000

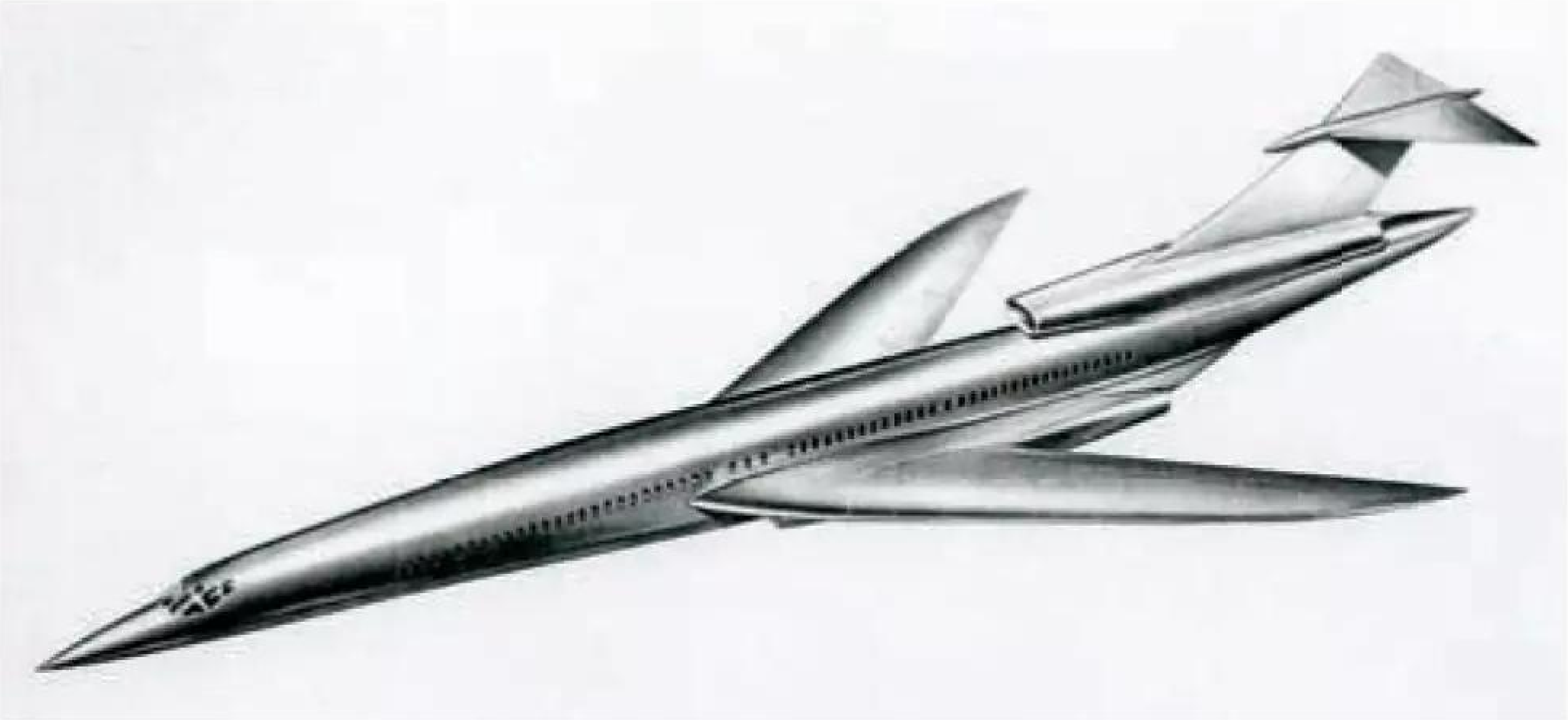
The Hawker Siddeley Advanced Projects Group's (APG) Type 1000 dated from 1960 and was an integrated wing project designed initially for Mach 2.2, though further studies went on to look at speeds of Mach 2.7. The wing leading edges extended along the sides of the forward fuselage and the six engines were under the rear wing. There was a tricycle undercarriage with 8-wheel main units and twin-wheel nose gear. Like Bristol, HSA also looked into VTOL capability but in Hawker Siddeley's opinion the necessary powerplant, and the noise that this would have created, made the idea impractical, at least for the first generation SST.



Artwork showing the HS 1011 with its wings forward. Note the four-engine powerplant arrangement. *National Aerospace Library*

HSA TYPE 1011

Much of the research undertaken by the APG at Kingston for a medium-long range transonic speed transport came



Manufacturer's artwork showing the HS 1011 with its wings swept. *National Aerospace Library*

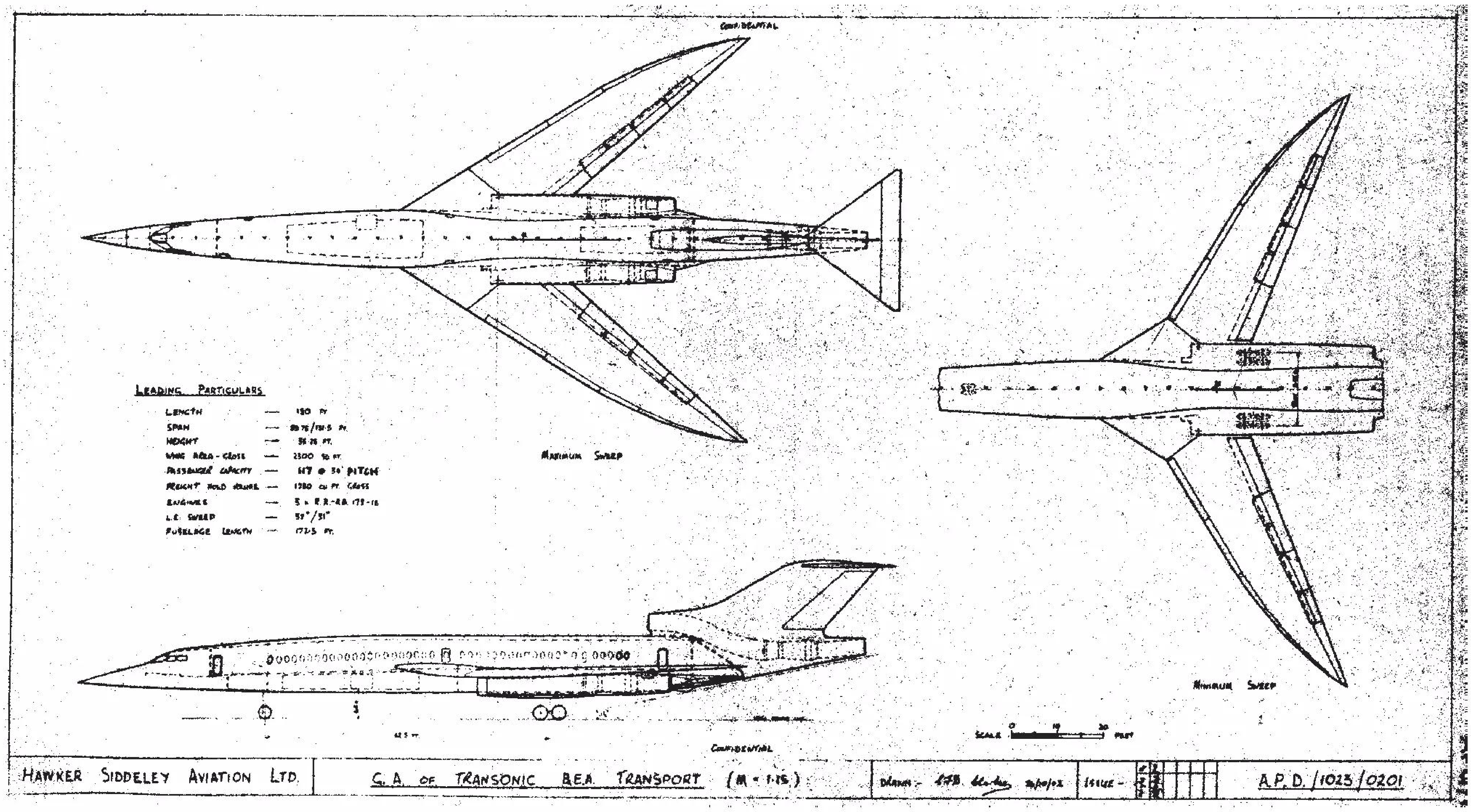
under the designation Type 1011, a Mach 1.15 aircraft. In a June 1961 report it was noted that Mach 1.15 had been chosen for the same reason that Handley Page had chosen it for the HP.128: to mitigate the effect of sonic booms on the ground and appeal to carriers whose routes were primarily overland.

It was generally agreed that to obtain good aerodynamic efficiency at Mach 1.15 a mean wing sweep angle of about 55° and a fairly low aspect ratio. Unfortunately, the low-speed lift and handling characteristics of this sort of wing were poor. The APG suggested that flap blowing would be impractical and the other alternative of a greater wing area was undesirable due to the consequent weight penalty. Like Vickers, Hawker Siddeley therefore concluded that variable wing sweep could provide the answer – sweeping forward to about 31° at low speed for better handling and back to 58° at supersonic speed for reduced drag.

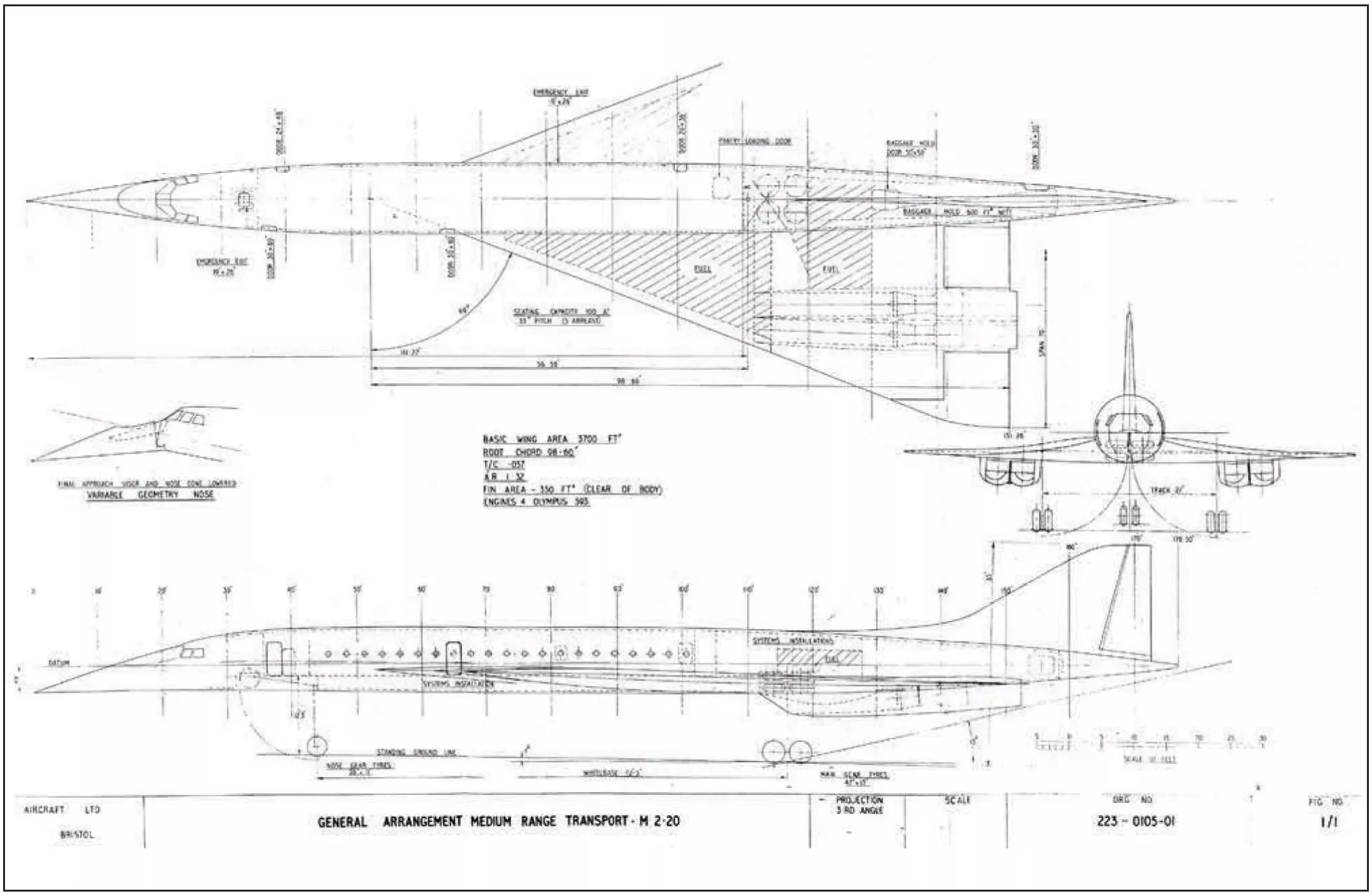
Four ducted-fan engines would provide for high efficiency at Mach 1.15. The Type 1011 would carry 160 economy class passengers, plus freight, over a stage length of about 2,500nm (4,633km). Under ISA sea level conditions, approach speed was 136 knots (252km/h) at a landing weight of 200,000lb (90,720kg) and estimated landing distance was 4,040ft (1,231m) from a 50ft (15.2m) altitude, giving a landing field length of 6,600ft (2,012m).

At the maximum take-off weight of 267,000lb (121,111kg) under ISA sea level conditions the all-engine take-off distance was 5,050ft (1,539m) and the balanced field length 6,260ft (1,908m). Maximum cruising speed with wings swept was Mach 1.15 under ISA conditions, a speed increase of about 30% over existing types. The airframe temperatures at Mach 1.15 would not create any concerns and the aircraft's systems would not require any development beyond existing technology, so proven equipment could be used throughout. With the exception of the fuselage centre section and wing root, the aircraft's structure would be of conventional construction and materials.

The pressure cabin was basically of circular section and 'area-ruled' to a minimum diameter in the region of the wing. The underfloor area forward of the engine air intakes comprised baggage space and was fully pressurised, while the underfloor area aft of the variable geometry structure was also pressurised and used for freight stowage. A small T-tail was fitted; a total of 13,125gal (59,678lit) of useable fuel was available and an operational life of 30,000 hours was guaranteed.


CONFIDENTIAL
LEADING PARTICULARS
LENGTH — 180 FT
SPAN — 80.75/118.5 FT
HEIGHT — 35.75 FT.
WING AREA - GROSS — 2300 SQ FT
PASSENGER CAPACITY — 167 @ 34" PITCH
FREIGHT HOLD VOLUME — 1780 CU FT. GROSS
ENGINES — 3 x R.R.-RB 178-16
L.E. SWEEP — 57°/31°
FUSELAGE LENGTH — 172.5 FT.
MAXIMUM SWEEP
MINIMUM SWEEP
SCALE 0 10 20 FEET
CONFIDENTIAL
HAWKER SIDDELEY AVIATION LTD.
G.A. OF TRANSONIC B.E.A. TRANSPORT (M = 1.15)
DRAWN -
ISSUE -
A.P.D. /1023/0201

Hawker Siddeley Type 1023 (12.12.62). *National Aerospace Library*


EMERGENCY EXIT
EMERGENCY EXIT
GALLEY LOADING DOOR
BAGGAGE HOLD
FUEL
FUEL
SEATING CAPACITY 100 A'
35" PITCH (5 ABREAST)
FINAL APPROACH VISOR AND NOSE CONE LOWERED
VARIABLE GEOMETRY NOSE
BASIC WING AREA 3700 FT²
ROOT CHORD 98·60'
T/C ·037
A.R. 1·32
FIN AREA – 350 FT² (CLEAR OF BODY)
ENGINES 4 OLYMPUS 593
DATUM
SYSTEMS INSTALLATION
SYSTEMS INSTALLATION
STANDING GROUND LINE
NOSE GEAR TYRES
WHEELBASE
MAIN GEAR TYRES
SCALE OF FEET
AIRCRAFT LTD
BRISTOL
GENERAL ARRANGEMENT MEDIUM RANGE TRANSPORT - M 2·20
PROJECTION 3 RD ANGLE
SCALE
DRG NO
223 – 0105-01
FIG NO
1/1

Bristol Type 223 (9.61). *Bristol Aero Collection*

HSA TYPE 1023

From discussions between Hawker Siddeley and BEA it appeared that the airline had a future requirement for a supersonic aircraft capable of carrying 100 passengers non-stop over about 1,500 miles (2,413km). Over such stages BEA could expect competition from developments of the American Boeing 727, the French Sud Caravelle and the UK's de Havilland Trident, as well as the Anglo-French Concorde (which by the time this brochure was put together was becoming a concrete programme). Such aircraft as Concorde might not be intended for stages as low as 1,500 miles (2,413km), but once again these supersonic transports might be held down in speed to avoid the sonic boom.

The Type 1023 project of December 1962, a smaller version of the Type 1011, would cruise at Mach 1.15 and could still be presented as a 'supersonic' airliner. Over the stage length considered it would offer considerable savings in time compared to existing subsonic aircraft, and would not take much longer to complete the journey than the faster supersonic aircraft. In fact the time saved amounted to one half hour over a 1,000 mile (1,609km) stage. This aeroplane could cruise at Mach 0.95-1.15 (10% to 34% faster than subsonic aircraft), the design stage length varying with speed from 1,000 to 2,250 miles (1,609km to 3,620km). Fuel load totalled 65,000lb (29,484kg).

BRISTOL TYPE 223

By September 1961 there was a feeling that the BAC 198 was growing too big and might have to be scaled down. Moreover, a completely new proposal, the BAC 223, was now being examined as a possible basis for a common aircraft project, with both medium and long range variants. Bristol's independent four-engine Type 223 project of September 1961 was similar in its overall design, and in the arrangement of its systems, to the larger Type 198, but it was designed for transatlantic routes. It was of basically aluminium construction and would cruise at Mach 2.2 over ranges of around 2,400nm (4,447km). The 223 had a cargo bay of 750cu ft (21.23cu m) capacity and a tricycle undercarriage with four-wheel main units and twin nose wheels.

The engines, beneath the wings, had separate intakes of internal/external compression type with thrust reversers available for each engine, and a total of 110,900lb (50,304kg) of fuel was carried in four wing and three fuselage tanks. Wing sweep angle at the leading edge was 69° and the nose was designed to droop for low speed flight. In due course it was the Bristol Type 223 which was selected as the basis for a transatlantic supersonic transport design for the UK. The project had much in common with the resulting Concorde, and along with the French Super Caravelle would of course be developed into that aircraft. In 1960, however, the two main 'contenders' were the Bristol 198 and the HS 1000. ◆

2

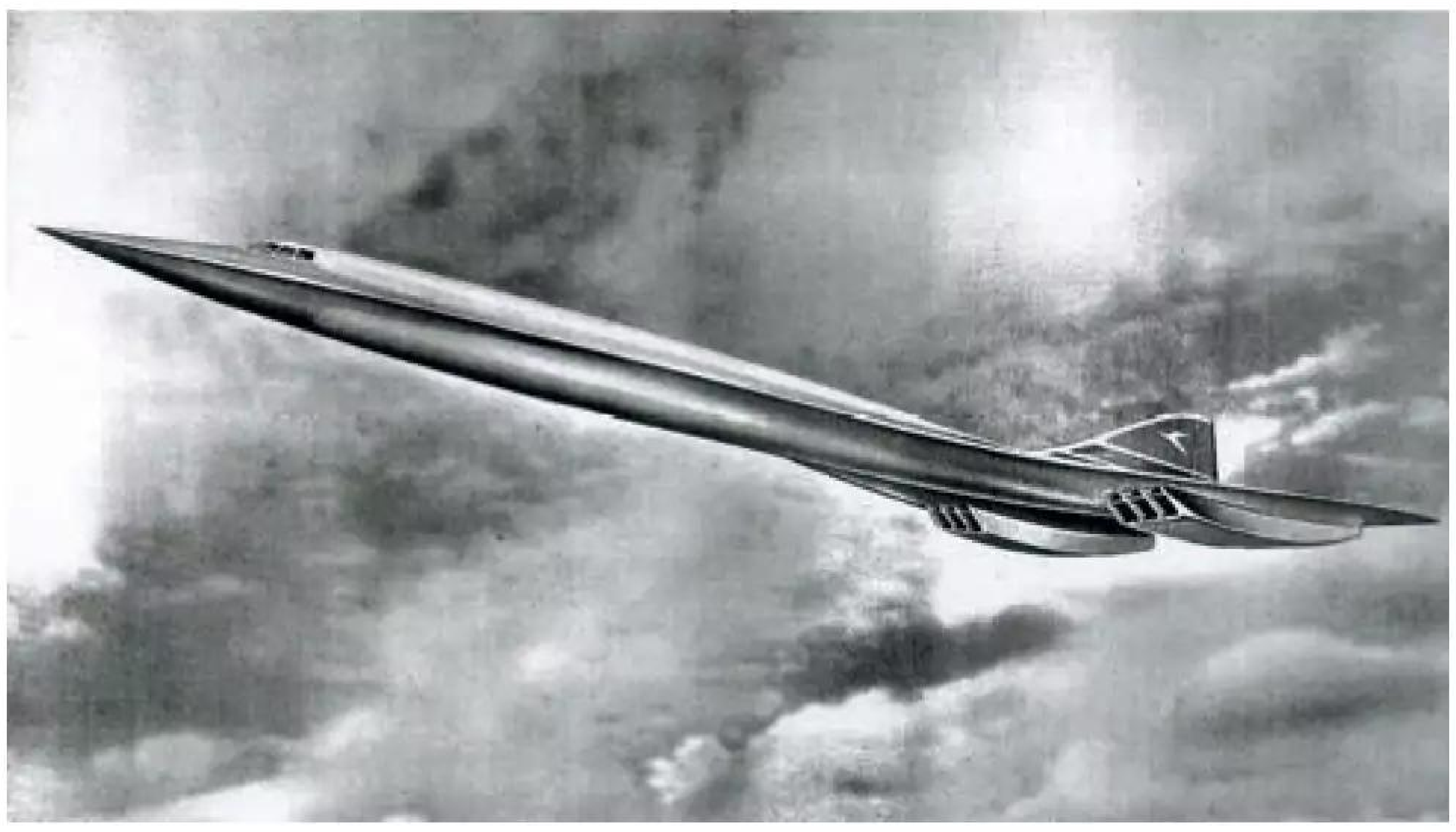
British Progress to 1962

An early display model of the Concorde. *George Cox*

While STAC had settled on the lower supersonic speed range for short-haul operations – Mach 1.2 – BEA's considered policy was that a much higher supersonic cruising performance should be the objective for all types of operation for which supersonic performance was feasible. By this time there were fairly clear indications that supersonic transport aircraft developments in the United States would be directed initially at speeds in the region of Mach 3.

If America's intentions were confirmed then it would be most unwise for the UK to develop an aeroplane in the Mach 1.2 category. Although the block time differences between Mach 1.2 and Mach 3 aircraft on all but the longest BEA routes would be small, and the operating problems of the former might be considerably less, if the economic characteristics of the two were comparable then there was no question in the airline's mind that the slower aircraft would not be competitive with the faster type, even on stages as short as BEA's longer routes.

The only other possible justification for embarking on a British Mach 1.2 aircraft would be if it could be brought into service sufficiently ahead of a faster American aircraft for it to have a useful life, before it was made obsolete by faster aircraft of comparable economic characteristics. However, in view of the very much greater American resources and the fact that they were already building a large military aircraft with a potential Mach 3 performance (the North American XB-70 bomber), it seemed unlikely that a sufficient lead in time could be achieved with a British Mach 1.2 project to make it worth pursuing. BEA's conclusion was that if a British supersonic transport project was to be undertaken then it should be aimed at the Mach 3 performance bracket. If the Americans did establish Mach 3 as their next step in transport aircraft performance then it would be quite futile for the UK to attempt its own independent more modest step.



Original manufacturer's artwork for the Hawker Siddeley Type 1000. *National Archives via Richard Payne*

Bristol involvement in the SST was helped by the firm's strong background in the design of civilian airliners. One example was of course the huge Brabazon piston-powered airliner which first flew on 4 September 1949. *Bristol Aircraft*

BRISTOL
BRITANNIA

Another Bristol airliner was the beautiful turboprop Britannia which first flew on 16 August 1952. This view shows the first Series 310 G-AOVA which first became airborne on the last day of 1956. *Bristol Aircraft*

BRISTOL BRITANNIA 301
Bristol
BRITANNIA

Britannia Series 301 G-ANCA touches down at Farnborough during the September 1957 Show.

BRISTOL (BAC) 198 AND HSA TYPE 1000

The Bristol 198 and Hawker Siddeley Type 1000 became the subjects of expanded feasibility studies commissioned by the MoS in 1959. The completed feasibility studies undertaken by BAC (Bristol) and HSA were submitted by the end of March 1960 and were then subjected to detailed technical scrutiny by the RAE. In the meantime the Air Transport Electronics Council had set up four committees to study the special requirements of ground and air equipment to meet the future needs of civil aviation, with each committee including experts from the electronics industry, the aircraft industry and the airlines.

The design proposals were reviewed at a meeting held at the Ministry of Aviation, St Giles Court, on 24 May 1960. Each group had studied designs for both Mach 2.2 and then Mach 2.7 to 2.8 capability, but more work has been put into the Mach 2.2 designs (and thus more confidence could be placed in them) whereas the Mach 2.7/2.8 layouts were sketchier and the assessors had found it difficult to extract useful data from their brochures.

Both Mach 2.2 designs used the slender-wing concept on a light alloy aircraft. The HSA proposal was for an 'integrated' design with the body and wing blended, whereas the BAC 198 had a more distinct wing plus a body. The HSA Mach 2.7 proposal had the same aerodynamic characteristics as its Mach 2.2 version but was to be built in steel with a larger wing area, while the BAC Mach 2.8 design, for which two separate proposals were put forward in steel and in titanium, extended the slender wing concept some way towards a shock interference layout.

Britain's and the world's first jet airliner was the de Havilland Comet. The example seen here is G-ALYP which was one of the Comet 1's tragically lost in crashes brought about by metal fatigue, in this case in January 1954. Necessary modifications made to the Comet to produce a secure airframe saw the Americans subsequently take the lead in jet airliner development with the Boeing 707 and Douglas DC-8. Part of the driving force which brought forth the development of Concorde was the desire for Europe to regain that lead.

These five types had the following characteristics:

Type	Passengers	Length	Span	All-up weight	Total fuel	Cruise speed
Type 198 (aluminium airframe)	122	171ft (52.12m)	97ft (29.57m)	330,800lb (150,051kg)	149,700lb (67,904kg)	Mach 2.2
HS 1000 (aluminium airframe)	100	179ft (54.56m)	74ft 7in (22.74m)	314,000lb (142,430kg)	151,900lb (77,974kg)	Mach 2.2
Type 198 (steel airframe)	120	200ft (60.96m)	100ft (30.48m)	446,070lb (202,337kg)	229,440lb (104,074kg)	Mach 2.8
Type 198 (titanium airframe)	120	200ft (60.96m)	100ft (30.48m)	408,250lb (185,182kg)	210,250lb (95,369kg)	Mach 2.8
HS 1000 (steel airframe)	100	193ft (58.83m)	80ft 7in (24.57m)	331,000lb (150,142kg)	157,600lb (71,487kg)	Mach 2.7

The choice of speeds was dictated by materials considerations. The speed for the steel aircraft was limited to Mach 2.7 because this was thought to be the UK maximum for the non-metallic materials used in the aircraft, with the safety margins appropriate to civil flying and the need for durability (the Americans proposed to use metallic sealants in their Mach 3 design but for safety reasons this seemed unacceptable in civil aircraft).

However, the detailed investigations had shown that, over most of the structure, the loadings and required ultimate stresses were very low and it was therefore practicable to aim from the outset at Mach 2.2 for a light alloy structure, rather than the Mach 1.8 previously recommended by the STAC report. The assessments had also indicated that the direct operating costs of the Mach 2.7 type were much more than for Mach 2.2, partly because the main structural material was steel.

So since the STAC report had been issued, the ‘speed gap’ between the aluminium alloy and steel aircraft had been narrowed considerably and it was even thought that Mach 2.2 might not now be the ultimate limit to which a light alloy structure could be developed. Moreover, a Mach 2.7 aircraft would be less than half an hour quicker over the transatlantic journey but would involve a substantial increase in operating costs.

The meeting concluded therefore that, on the evidence available, technical judgment was heavily in favour of a Mach 2.2 light alloy aircraft. Early on the original choice had been between Mach 1.8 and Mach 3 and the increase in speed of the light alloy aircraft to Mach 2.2 or higher was significant. Now be it would difficult to justify a choice based solely on a speed criteria when this had to be associated with a rapidly increasing development risk and operating costs. However, it was considered that the possibility of going to Mach 2.7 in co-operation with America should not be ruled out.

The RAE had confirmed that lateral control at low speed was a difficulty for both designs, as evidenced by the difficulty of controlling roll deviation within acceptable limits in a 15 knot (28km/h) side gust. This was the worst of the aerodynamic problems, but it was not insoluble. RAE deputy director Handel Davies said it was a matter of judgement as to how the problem should be tackled. The facts were well known, but the characteristics shown up by the studies were not good and a high rolling moment in a cross wind was evident. An extensive test programme might be necessary to resolve these difficulties. Reduction of rolling moment due to sideslip by the adoption of a ‘gull-wing’ form, further investigation of the best roll-control power and rate of application, and improved methods of roll autostabilisation all needed to be pursued actively to help deal with the problem.

Looking more closely at the individual designs, RAE had reported that the BAC proposal had clear advantages. For example, for a given volume, a much bigger fraction of the aircraft was well placed for accommodating passengers and its wing was not so thick at the root. Both firms had used the slender wing concept for their Mach 2.2 designs, significant differences being the larger span/length ratio of the BAC design and the larger number of passengers carried in a structure of about equal length and wing area.

HSA had argued that the same aerodynamic characteristics could be used in a Mach 2.7 design but built in steel with a larger wing area, and so they had kept the span/length ratio and wing loading down for their Mach 2.2 project. BAC found that putting the engine box below the wing and away from the centreline allowed another 20 passengers to be accommodated within a slightly smaller overall length.

Discussions with the firms indicated that BAC had given more thought to the problem of putting passengers into the

Handel Davies, the Deputy Director of RAE Farnborough from 1959. *Colin Rees, Aberdare Boys Grammar School*

volume, while the HSA parametric studies were useful for indicating trends but the study of the detailed utilisation of the available volume had not been taken as far. BAC had proposed two designs in steel and titanium, the titanium cost per pound (kilogram) being 35% greater, although this version's empty weight and fuel weight were less thereby giving roughly equal direct operating costs.

THE ENGINES

On the engine side, both airframe groups preferred a development of the Olympus engine for the Mach 2.2 aircraft. For this choice the quoted performance could be achieved from the Olympus 591/2 on the assumption that air cooled turbine rotor blading made from cast materials could be developed to withstand the high turbine entry temperatures proposed for the cruise condition.

The engine designs considered for the Mach 2.7 aircraft spanned a wider field and included ducted fan engines for the purpose of alleviating the noise problem. For Mach 2.7 HSA had chosen the BS.84 (a proposed ducted fan engine with bypass reheat) while BAC at Mach 2.8 had the BE.58/11R (an earlier version of the BS.84). In comparison with reheated and unreheated turbojets, the aircraft firms found that the ducted fan designs gave aircraft lower noise levels with only a small penalty in all-up weight.

However, the RAE stated that the bases on which Bristol Siddeley had estimated the performance of this engine were unsatisfactory. As such, the engine data position was much less certain for the Mach 2.7 aircraft with ducted fan engines than for the turbojet-engined Mach 2.2 project.

On the matter of installation, there was at this stage no substantial difference between the two sets of proposals for the Mach 2.2 aircraft. Design features applied were firmly based on the philosophy of the STAC report: 1) A part-buried, rear-wing arrangement was preferred, since this offered the possibility of low installed drag. 2) A bleed duct for diversion of the wing boundary layer, necessary for the achievement of adequate pressure recovery in the intakes. 3) Variable geometry intakes to minimise the drag at cruise speed and allow efficient matching of intake and engine at lower speeds.

In both cases the six engines were grouped in threes and mounted in a side-by-side arrangement in two nacelles, one under each wing and fairly well outboard. Both firms had chosen an underwing rather than an overwing installation, recent results from the research programme having shown that this reduced local Mach number at the inlets. However, guards would have to be developed to prevent ingestion of stones and slush on the runway, and in the meantime aileron effectiveness had suffered.

The committee considered that the Bristol proposals had been thought out more carefully than those of Hawker Siddeley but the basic installations were so similar that this could be expected not to matter in the long run. Both firms had shown a proper awareness of the ingestion problem, but neither was considered particularly reassuring in regard to their solution.

Developing sufficient engine cooling would not be easy but the main problem was likely to be that of noise. With powerful high thrust engines the proposed aircraft would inevitably be noisy on take-off and landing. There was a good prospect of keeping within the limits imposed at flyover checkpoints (about 4 miles/6.5km from the airfield), but lateral noise during the take-off run would most probably be higher than that of existing subsonic jets.

In fact, ground take-off noise level was estimated to be around 20dB greater than that generated by the subsonic Rolls-Royce Conway-engined Boeing 707 with noise suppressors, and around 10dB when in flight. This severe problem, which BAC in particular had underestimated, concerned the use of the Olympus 591. The alternative of using a quieter, high-bypass-ratio engine had therefore to be seriously considered though evidence suggested that this would increase the R&D cost by only a small fraction, and might well not delay the aircraft's first flight. At the same time, vigorous research on finding a form of noise suppression compatible with variable nozzle geometry was considered extremely desirable.

The engine noise data available for the Mach 2.7/2.8 aircraft was much less certain than that for the Mach 2.2 type. The preference for ducted fan engines did give reduced engine noise, but even so the take-off noise level was still estimated to be 10dB above the Boeing 707. The question of intake noise during the throttled landing condition was another aspect which needed to be considered.

For the Mach 2.2 design the time needed to reach first flight was assessed by the committee as 5-7 years, with another 2-3 years to reach an initial C of A (Certificate of Airworthiness). Committee member A. S. Crouch considered that the quoted BAC date to first flight was more realistic than the HSA date. His estimate was about 6.5-7 years from date of contract which agreed closely with that of BAC, when Hawker Siddeley's estimate had been only about 5 years.

BAC estimates of the total flying time and the programme for C of A flying was also more rational than that proposed by HSA, who had projected a build up of 12 aircraft in the first 26 months. It was considered impracticable to have such a large number of aircraft flying in the early stages of development, but it was agreed that it was desirable to have the first three or four aircraft as soon as possible. For Mach 2.7/2.8 it was suggested that the time to achieve the first flight might be 6.5-8.5 years, plus another 2.5-4 years to initial C of A.

BAC had concluded with a strong preference for the Mach 2.2 whereas HSA had stated that they wished to continue work on both designs, believing that the Mach 2.7 aircraft offered a number of attractions and might be the better choice. However, RAE had rejected HSA's recommendations for a study of a steel aeroplane.

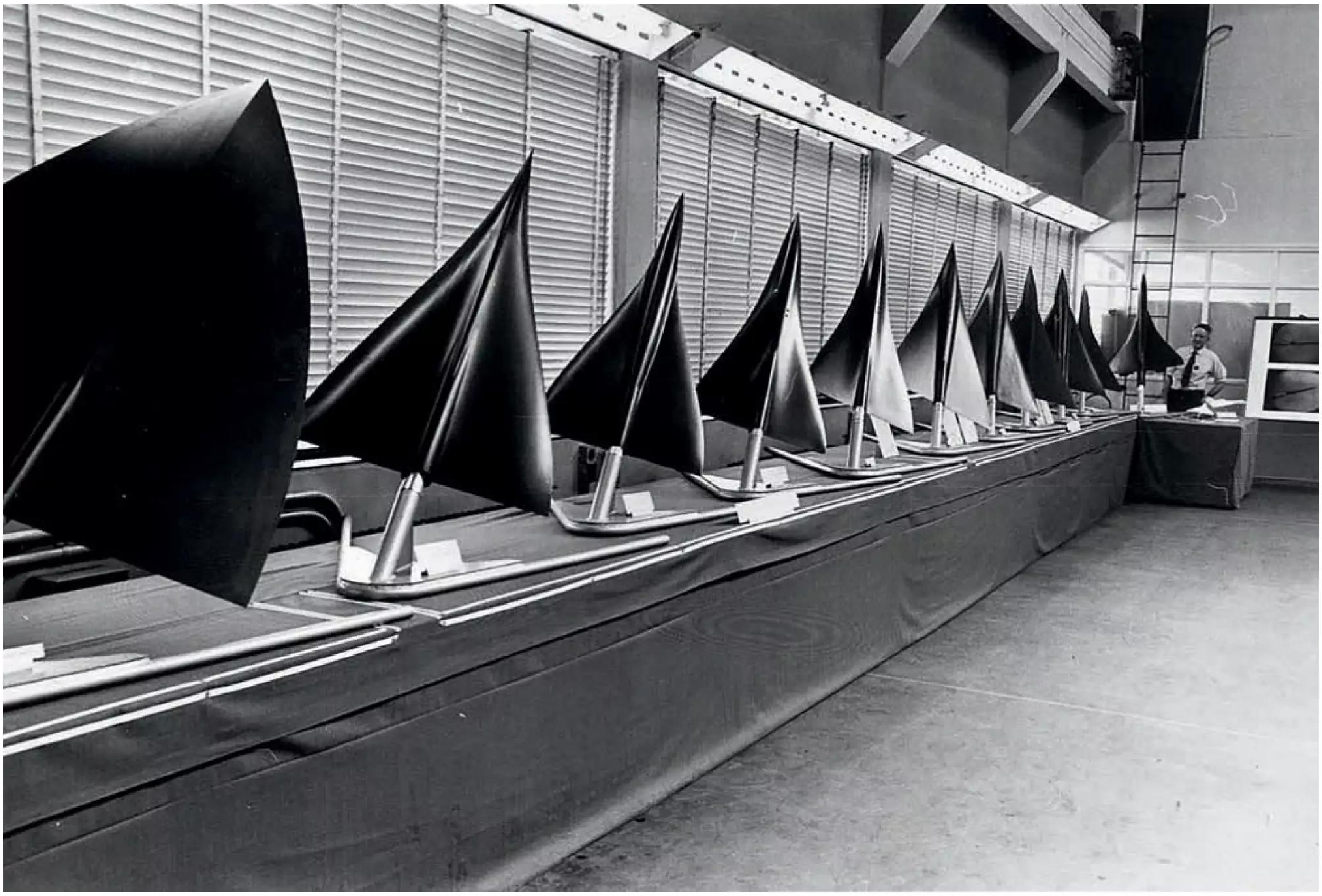
BAC VERSUS HSA

The head of the RAE's Aerodynamics Department, Lewis F. Nicholson, thought that organisationally there was little to choose between the two aircraft groups, but Controller Aircraft (CA) Sir George Gardner emphasized the need to consider the personalities who might be engaged on a supersonic project. BAC had produced a better design and in Gardner's opinion had more experience of supersonic design. It was agreed that the BAC study was technically superior and this was no doubt to the credit of (chief designer) Dr Russell. On the other hand, it was known that BAC chief Sir George Edwards was not enthusiastic about the supersonic aircraft – potentially a serious handicap.

On the economic side, it was assumed that supersonic and subsonic aircraft would continue to operate in parallel with a fare differential between the two. The speed of a supersonic aircraft might, at least initially, carry great passenger prestige but cheaper subsonic jets might do better when it came to carrying mail and freight.

Sir George Edwards, managing director of BAC.

Dietrich Küchemann. *Royal Aeronautical Society*



Line up of models showing the numerous shapes considered by the designers for the Concorde wing. The eventual choice appears at the far end of the row. *BAE SYSTEMS Heritage, Farnborough*

It was concluded that the feasibility of a basically aluminium supersonic transport for flight at around Mach 2.2 had been established, and that such an aeroplane could be developed. BAC's timescale prediction, i.e. in service 1969-70, was accepted, and it was also considered that this aircraft would have good competitive chances against subsonic jets and against American civil B-70 type aircraft. Accordingly, it was recommended that a design contract should now be placed. It was noted, however, that although the two feasibility studies had been compared, no attempt had been made to compare the two firms in regard to their suitability for the award of this contract.

A further Ministry paper produced during 1962 observed that the first countries to produce a supersonic airliner would have to make the experiment and then bear the commercial consequences.

FINDING A SUPERSONIC WING

The SST feasibility studies highlighted the importance of choosing the correct wing planform – and for Mach 2.2 this was in both cases a slender wing with a span shorter than its chord or length. This wing had to be able to contend with Mach 2 speeds but also to provide enough lift to enable the aircraft to take-off and land safely at low speeds.

The principal research for the slender wing used in the feasibility studies was undertaken at RAE Farnborough by aerodynamicist Dietrich Küchemann working in close collaboration with Johanna Weber. Both Küchemann and Weber, key figures in the Concorde story, were born in Germany and during World War II had worked with one another at the German aerodynamics research institute at Göttingen. Both would make major contributions to the advance of high speed aerodynamics and flight in general, for example in the fields of drag, swept and delta wings and fuselage design. Küchemann moved to England in 1946 to join the staff of RAE Farnborough and Weber followed him there soon afterwards to continue a lifelong working partnership.

During the 1940s the development of high speed aircraft resulted in steady increases in wing sweepback, while wing thickness/chord ratios and wing aspect ratios came down. However, a major obstacle was the large amount of wave drag that was generated; could this be kept down by using slender wing shapes?

Küchemann advocated for long slender aerodynamic shapes which presented a minimum of frontal area to the air, producing a high enough lift/drag (L/D) ratio to provide economic cruise at speeds of Mach 2. The changes of air flow and trim during the transition from subsonic to supersonic flight were reduced, and would take place more gradually with wings swept back far enough so that the leading edges lay behind or inside the 'bow wave' generated at supersonic speeds.

To balance the centre of lift and centre of gravity, this wing had to be set back towards the rear end of the fuselage. The wing trailing edge then provided the area for the elevons, so a slender wing aircraft like Concorde was therefore tailless and in consequence could not use flaps. At one stage foreplanes had been claimed to offer certain advantages but these were not established in any convincing way.

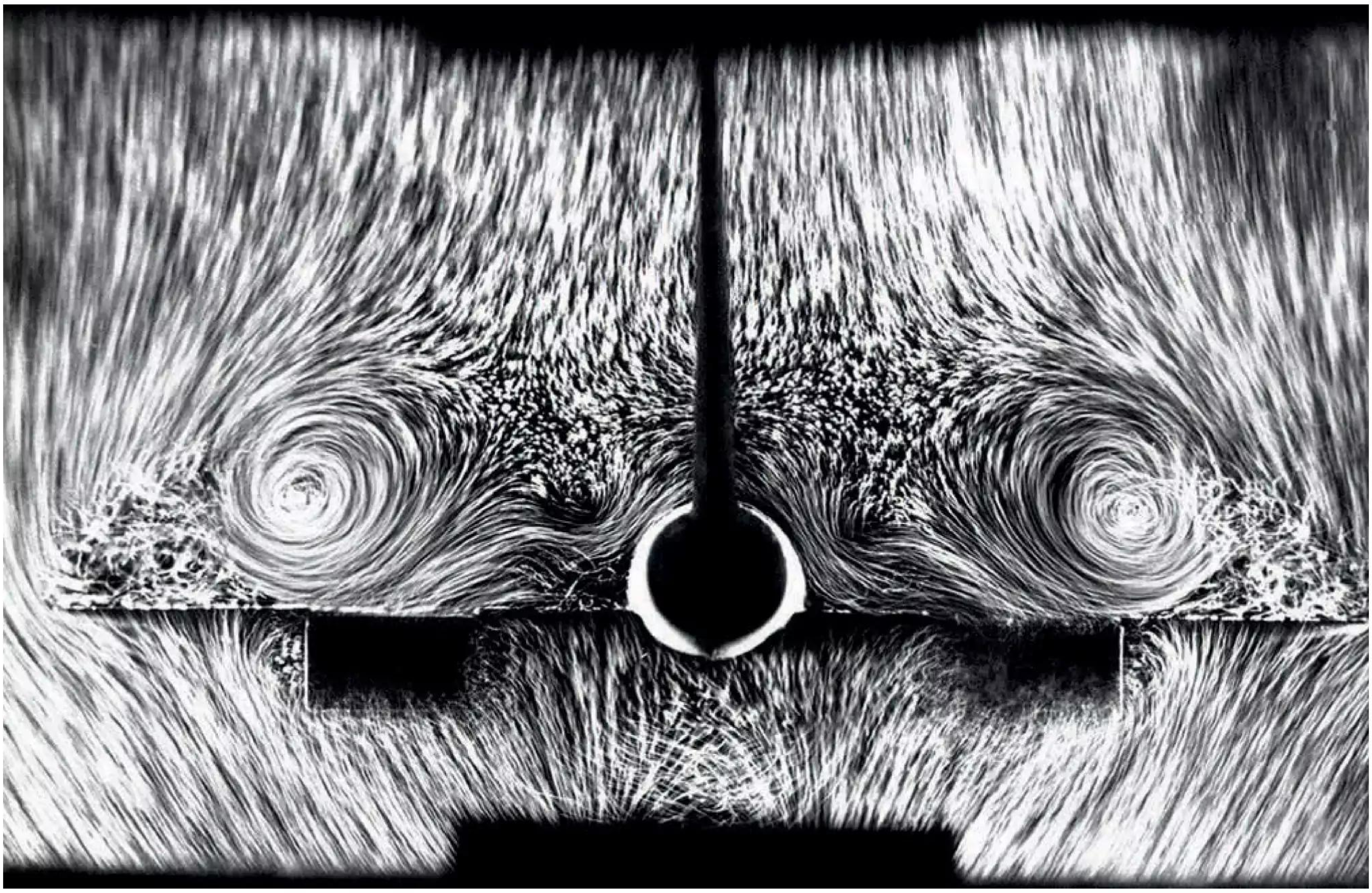
Nevertheless, during the early stages of STAC it was thought that such a slender low aspect ratio wing would make landing safely too difficult. Could such a wing also generate sufficient lift for the approach and landing to be made at low speeds? The design requirements at each end of the speed range for an aircraft fitted with a slender wing appeared to be in direct conflict.

Another element was that unwanted airflow separations would occur at quite moderate angles of attack (AoA) and bring big problems with longitudinal and lateral stability. Those separations originating from the swept leading edge would give the biggest trouble, taking the form of vortices which would coil up over the wing surface and bring undesirable changes to the distribution of the lift.

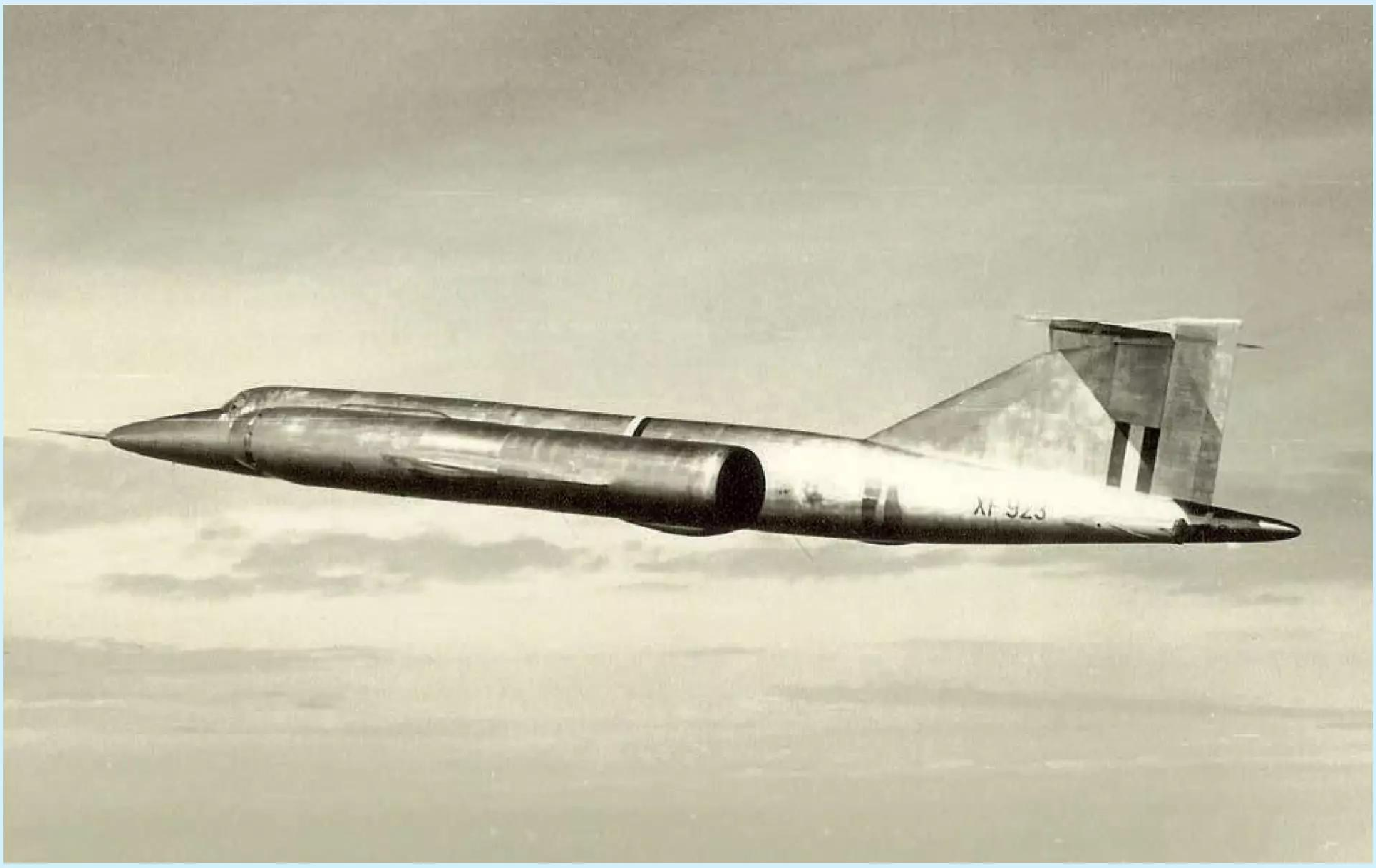
But in 1956 Küchemann, together with Eric Maskell of RAE, published paper which stressed the value of a slender delta with sharp leading edges. Here it could be possible to stimulate controlled separations and generate a stable system of leading edge vortices that would induce suction on the upper wing surface, and which would also stay constant along the wing chord until at least it approached the trailing edge.

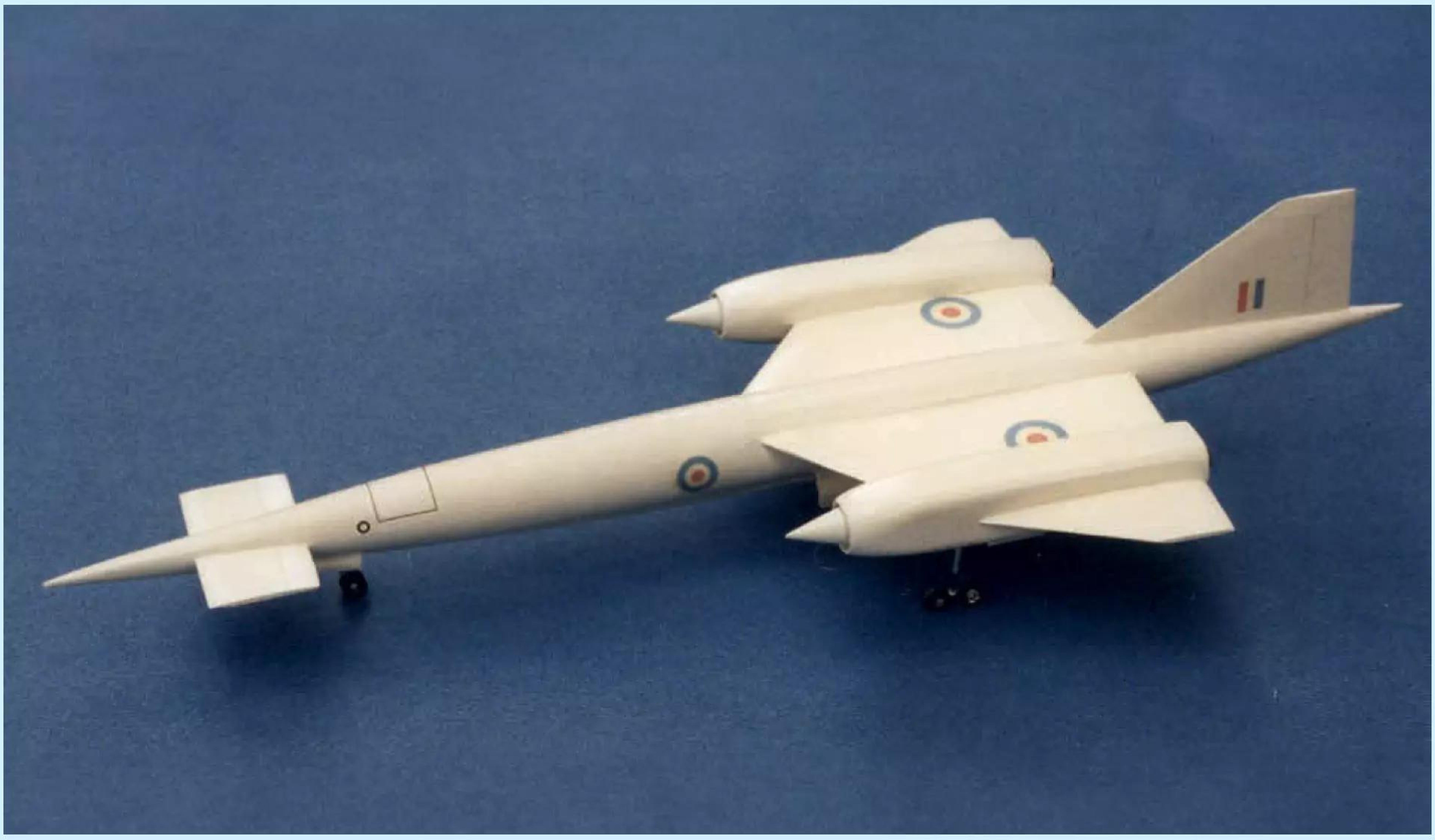
In addition, Weber's research revealed that a thin delta or slender wing flown at a high AoA could provide enough lift for the take-off and landing parts of a flight. In fact the vortex would reduce the air pressure and increase the lift to such an extent that this effect could be used deliberately to improve the wing's low speed performance. Fortunately for the SST, the aerodynamicists had found a wing shape that was not only ideally suited to economic supersonic cruise but also had a low-speed lifting capability that far exceeded expectations based on conventional aerofoil theory. Another noteworthy feature was the unusual magnitude of additional lift generated by the proximity of the ground during lift off and at touchdown.

There was a worry that trailing edge controls might not operate effectively beneath a well-developed vortex, but wind tunnel testing revealed that fairly conventional ailerons and elevators (elevons) would work. There was one downside to the wing now taking shape; to produce the



Rear view of a wind tunnel model showing vortexes over Concorde's upper wing surfaces.





Had Concorde been built in steel then the assembly of its structure would have drawn heavily on the experience of these two supersonic aeroplanes, the Bristol 188 research aircraft and Avro 730 bomber, both of which from a configuration point of view were very different to Concorde. The development of fabrication techniques brought considerable delays to the 188's flight test programme – ordered in 1954 as the world's first stainless steel aeroplane, the first example did not fly until 1962. The Avro 730 was also to have been built in steel but was cancelled early in its development programme and long before first flight. *Alan Jenner / John Hall respectively* required vortex lift, the aircraft would have to take off and land very 'nose high', so the undercarriage would require relatively long legs.

On a conventional aircraft it was usually possible to generate the lift required to maintain low speed flight by the use of flaps and without demanding high incidence, this being restricted by the stall. With a slender wing, however, when no stall would inhibit the use of high incidence, there was every incentive to use as high an incidence as possible. Unfortunately, stability and control would deteriorate with incidence and the view from the cockpit became obscured by the upraised nose.

Supersonic drag considerations required a sharply pointed nose no irregularities of contour – precluding the design of a conventional cockpit with an exposed windscreen. Limited direct forward vision might be accepted at high speeds, but in low speed flight the nose would obscure a vital area of downward view; restoring this meant the nose section would have to be drooped.

Putting the aircraft at high AoA would also result in a steep increase in drag, such that even the large amount of power installed in the SST could eventually become inadequate to maintain level flight at low speeds. And passengers and staff were said to be intolerant to attitudes greater than about 15°.

Even accepting these limitations, the data showed that a 250,000lb (113,400kg) SST with a wingspan of 80ft (24.38m) could take off and land at speeds comparable to those used by the present subsonic 'big jets'.

Küchemann and his colleagues had begun by considering three basic shapes, the 'conventional' straight-edged delta wing, the 'gothic delta' where the wing was curved outwards to form a shape resembling a gothic arch, and an 'ogival wing' with the rounded S-shape of an ogee curving in opposite ways. Each had aerodynamic advantages and disadvantages but it was to be the slender 'ogival wing' which found its way onto Concorde because this could form vortices directly at the leading edge.

This work changed the entire nature of supersonic wing design seemingly 'almost overnight', but in fact there is insufficient space here to describe the intensity and depth of the programme that led to this breakthrough. Over many months – even years – the effort involved a long series of wind tunnel tests using dozens of models, mediated at every stage by theoretical work to enable the results to be understood in fundamental physical terms.

In the end the resulting Concorde wing was a subtle 3-dimensional shape which is probably best appreciated from directly ahead. It must also be stressed that, besides the RAE effort, this particular field of aerodynamics was also researched in depth in France at ONERA (the Office National d'Etudes et Recherches Aérospatiales) and in America by NACA (the National Advisory Committee for Aeronautics).

THE HEAT BARRIER

Another critical factor was ensuring that the SST's airframe did not overheat. When an aircraft's forward motion compresses the air it also heats it up, and as speed increases the compression is accelerated, increasing the air temperature still further. Of course the airframe will also heat up, getting warmer as the aircraft flies faster.

This phenomenon, kinetic heating, manifests at all speeds but starts to become important once the aeroplane is supersonic; the areas affected most are the wing leading edges and engine intakes. At Mach 2 the temperature increase is about 175°C but at Mach 3 it goes up by 390°C. This must be combined with the static outside air temperature which above 37,000ft (11,278m) is around -55°C (depending on geographical location).

At Mach 2, parts of the airframe could reach 120°C. This would be a comfortable figure for selected aluminium alloys and require only relatively modest development work to yield a service life of perhaps 30,000 hours. This temperature would also come below the fuel-ignition points. But these light alloys would deteriorate in the heat at Mach 3, so the Mach 3 SST would require a titanium or steel structure. This would be expensive to produce and fabricate (titanium was rare and cost around ten times the price of aluminium). Also, inexperience in working with these high temperature materials for an airframe structure could result in a long and difficult programme.

Mach 2 flight would reduce the transatlantic crossing time by more than half – up to 4 hours – while Mach 3 would cut the journey time only by about another 40 minutes. This modest additional gain at Mach 3 would be more than offset by the hugely expensive airframe.

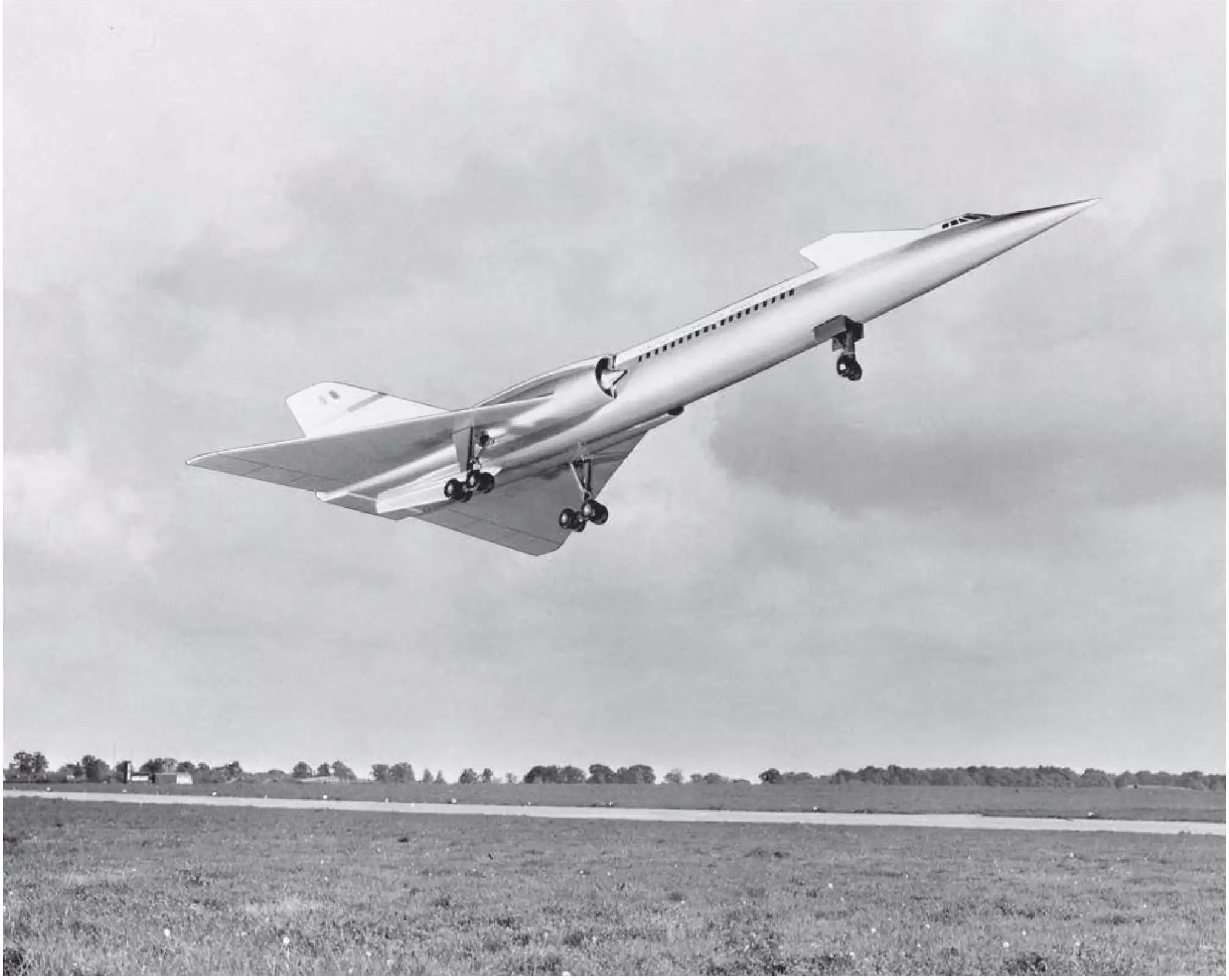
In the end a Mach 2.2 SST was about the best that British industry dared to attempt or could afford. **Ev**en by the start of the 1960s, plenty of criticism was being directed at the idea that the UK might press ahead with this type of aeroplane. Some critics highlighted the huge development cost while others argued that America's Mach 3 airliner would probably outsell a Mach 2 type, and so for many airlines the latter might appear as an unattractive alternative (assuming of course that the American product became reality). And would the public tolerate the sonic boom?

After the decision to build the joint BAC/Sud design which would become Concorde, research into supersonic transports by individual British design teams pretty well came to an end (with the exception of the Handley Page HP.128 which lasted into the mid-1960s). The work undertaken at Bristol would help form the basis for Concorde. Now it is time to take a look at what had been happening in France. ◆

3

Origins and Studies – France

By JC Carbonel



This splendid Dassault artwork depicts the manufacturer's Super Caravelle design after taking off. One can almost hear the roar of the four engines! *Dassault Aviation, Direction des Relations Extérieures et de la Communication*

France's ability to design and build new aircraft had stagnated during the German occupation of World War II, but a string of military jet prototypes had enabled the industry to catch up by the 1950s and the Dassault Company in particular began to win major orders for high performance combat aircraft.

The French Government eventually made arrangements with three manufacturers (Dassault, Nord and Sud) to examine the possibilities and to make proposals for a medium range supersonic aircraft, and a portion of the French SST effort would centre on nuclear propulsion. In France the SST concept was called the Transport Civil Supersonique or TCS.

Prior to work starting on France's SST research there had been some changes in the country's industry and its support facilities. Sud-Est (SNCASE) and Sud-Ouest (SNCASO) had merged on 1 March 1957 to form Sud Aviation with Georges Héreil as company president, while Arsenal (SFECMAS), Aero-Centre (SNCAC) and Nord (SNCAN) were joined together as Nord Aviation.

French aeronautical products were subject to Government evaluation, for which a complete range of experimental establishments were maintained who, in turn, made their experience available to industry. The official research establishment was called ONERA (the Office

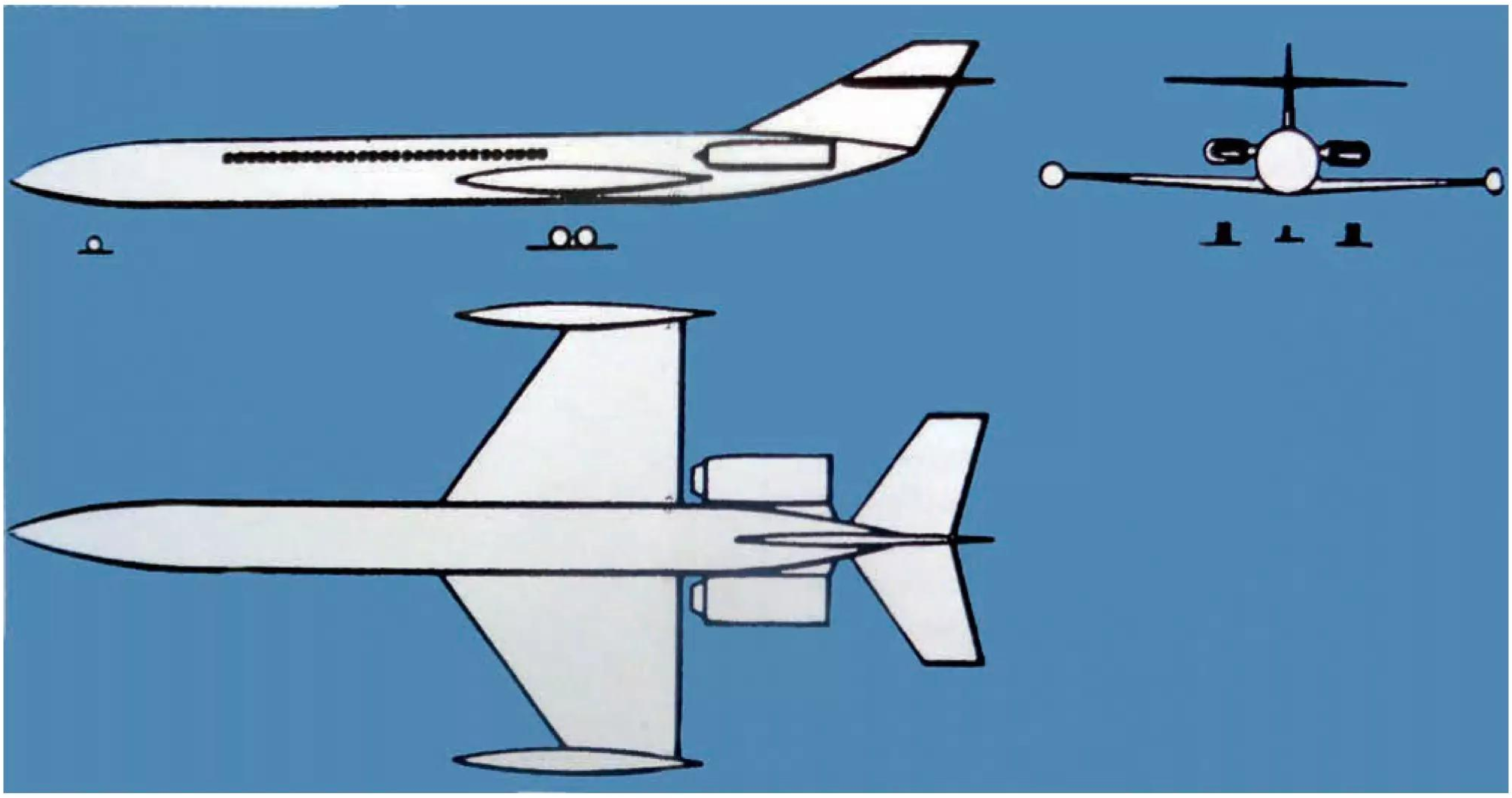
Georges Héreil was known as the 'father' of the subsonic French Caravelle airliner. As president of SNCASE (which in 1957 became Sud Aviation) he also pushed through the production of jet fighters and helicopters. But he was not a supporter of the Concorde project and in 1963 departed from Sud to move into the automobile industry. He was replaced by André Puget. *JC Carbonel*

National d'Études et Recherches Aéronautiques), while complete aircraft were officially tested by the CEV (Centre d'Essais en Vol) and engines by the CEP (Centre d'Essais de Propulseurs). The judgments of CEV and CEP were vital. If approval was given then their decision could see an aircraft reaching production, if not then improvements or modifications might be suggested to permit a second evaluation, but the CEV and CEP might refuse to accept a product altogether.

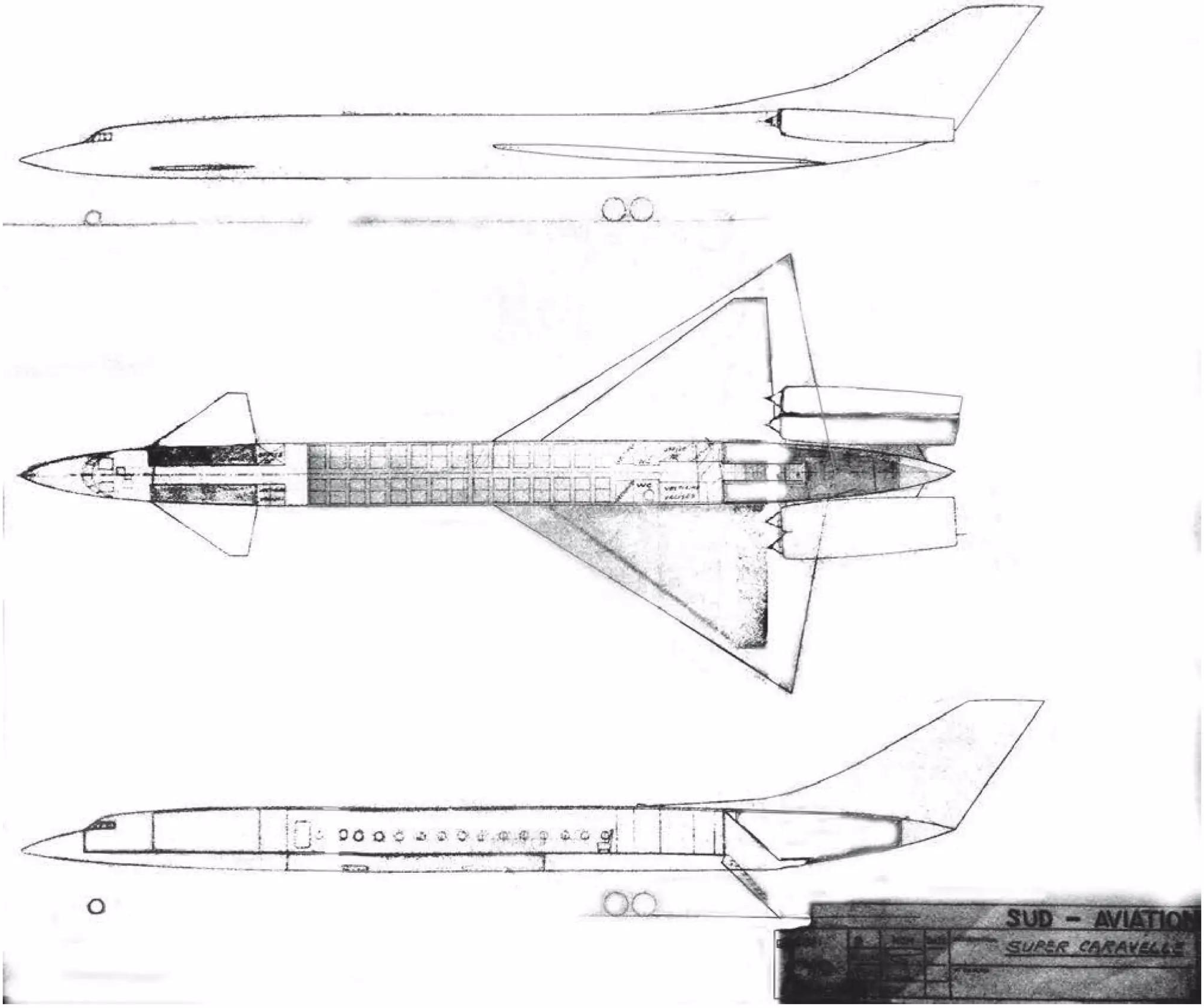
A central body called the DTIA (Direction Technique et Industrielle de Aéronautique), an equivalent to the old British MoS, was mainly responsible for equipment and material destined for the Armed Services, including supplying aeronautical requirements for the Air Force, Army and Navy, but it effectively also had control of France's entire aeronautical activity (all Directions Techniques – sea and ground forces, explosives, and air – were merged into the Direction Ministérielle à l'Armement in 1961). Finally the STAé (the Service technique de l'Aéronautique chargé de la partie technique, industrielle et administrative des marchés d'État) was responsible for coordinating all aeronautical studies and research in France.

SUD AVIATION X-225

It is understood that the first thoughts given to an SST project came in late 1957 from the Toulouse branch of the SNCASO design office led by Technical Director André Vaultier. On 15 January 1958 a brochure describing a Mach 1.8 60-passenger aircraft with a 3,000km (1,865 miles) range



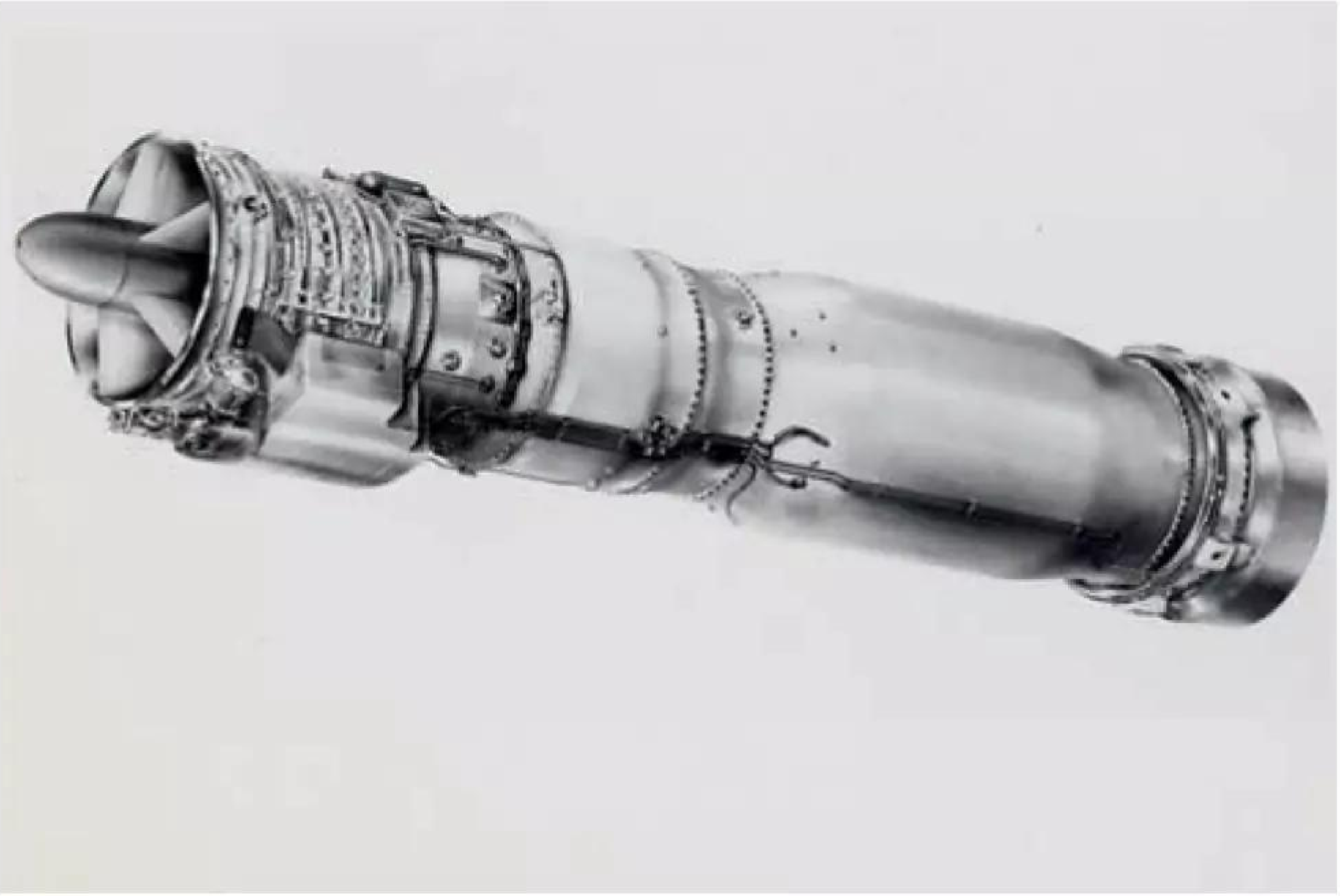
According to Pierre Sparacco's book *le Concorde: la véritable histoire,* this drawing is supposed to depict the very first design of the Sud Super Caravelle. *JC Carbonel*



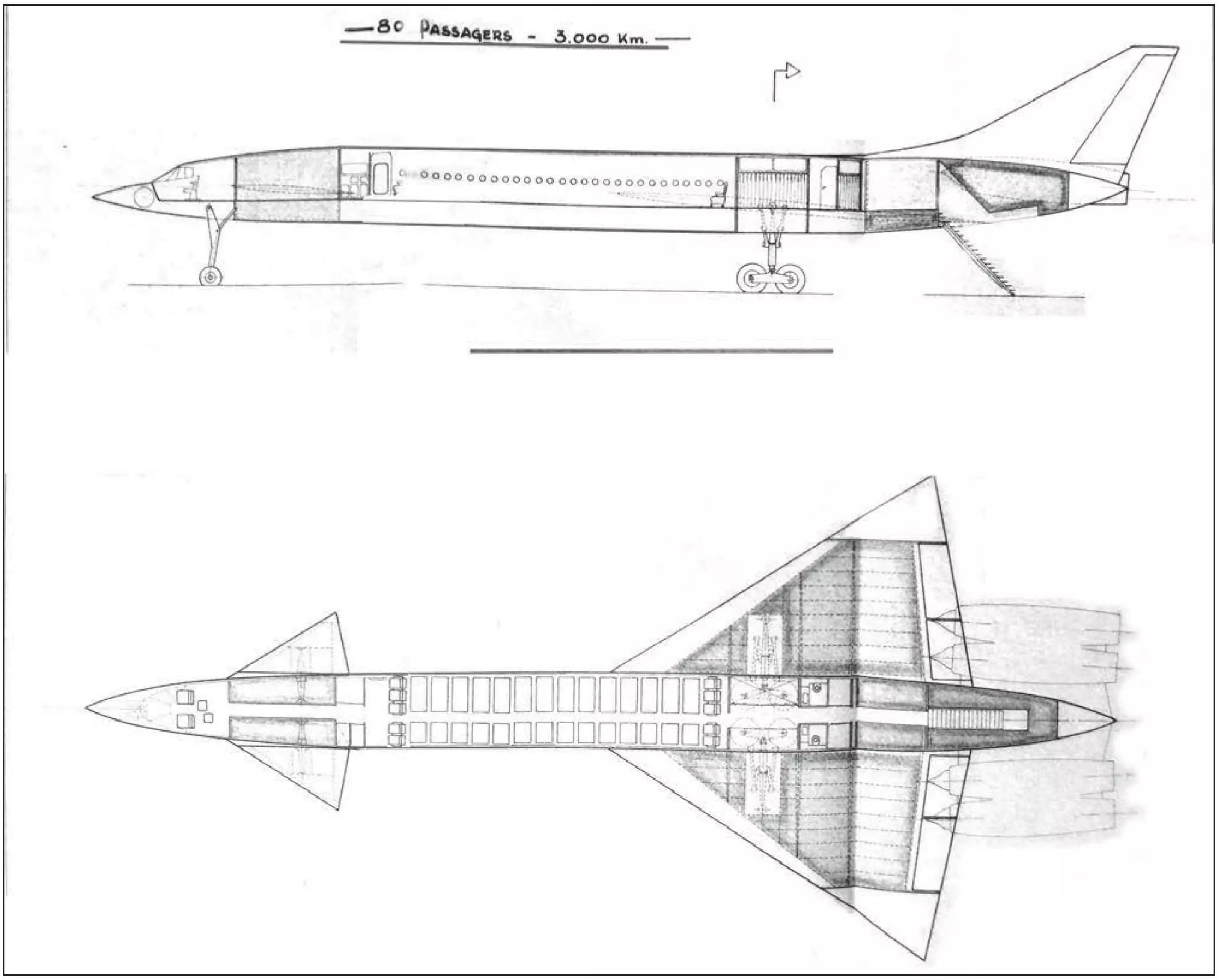
Three-view drawing of the early version of the Super Caravelle from 1958. This aircraft was intended to carry 60 passengers and, although quoted as having a delta wing, the shape was more reminiscent of a diamond. *Sud Aviation via JC Carbonel*

was shown to Charles Parot, head of the SNCASO transport/commercial projects design office. The powerplant was to be 5 or 6 ‘Super Atar’ engines with 23,000-26,000lb (102.2-115.6kN) thrust each. The ‘Super Atar’ was a rather nebulous turbojet designed but never perfected by SNECMA but this SST study did confirm that, from the basic elements of aerodynamics, weight and propulsion, a supersonic airliner was technically feasible.

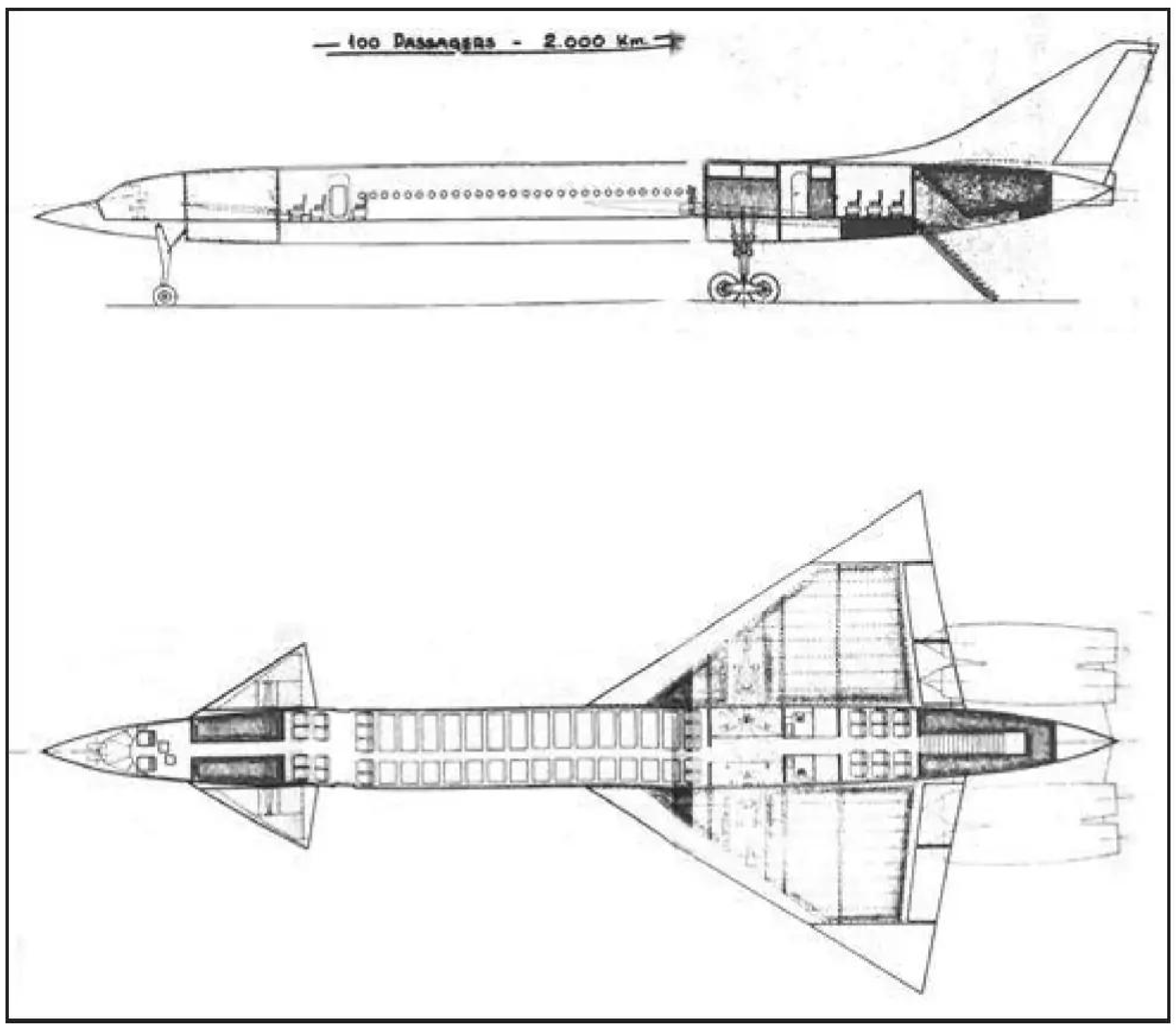
Meanwhile, one of the first French civil aircraft to attract the attention of the media outside France was SNCASE’s SE 210 Caravelle. This medium-range airliner had first flown on 27 May 1955 and by the end of 1957 sales had been made to Air France, SAS (Scandinavian Airlines) and Varig. Considerable interest was also shown in the type during a tour of the USA made in April.



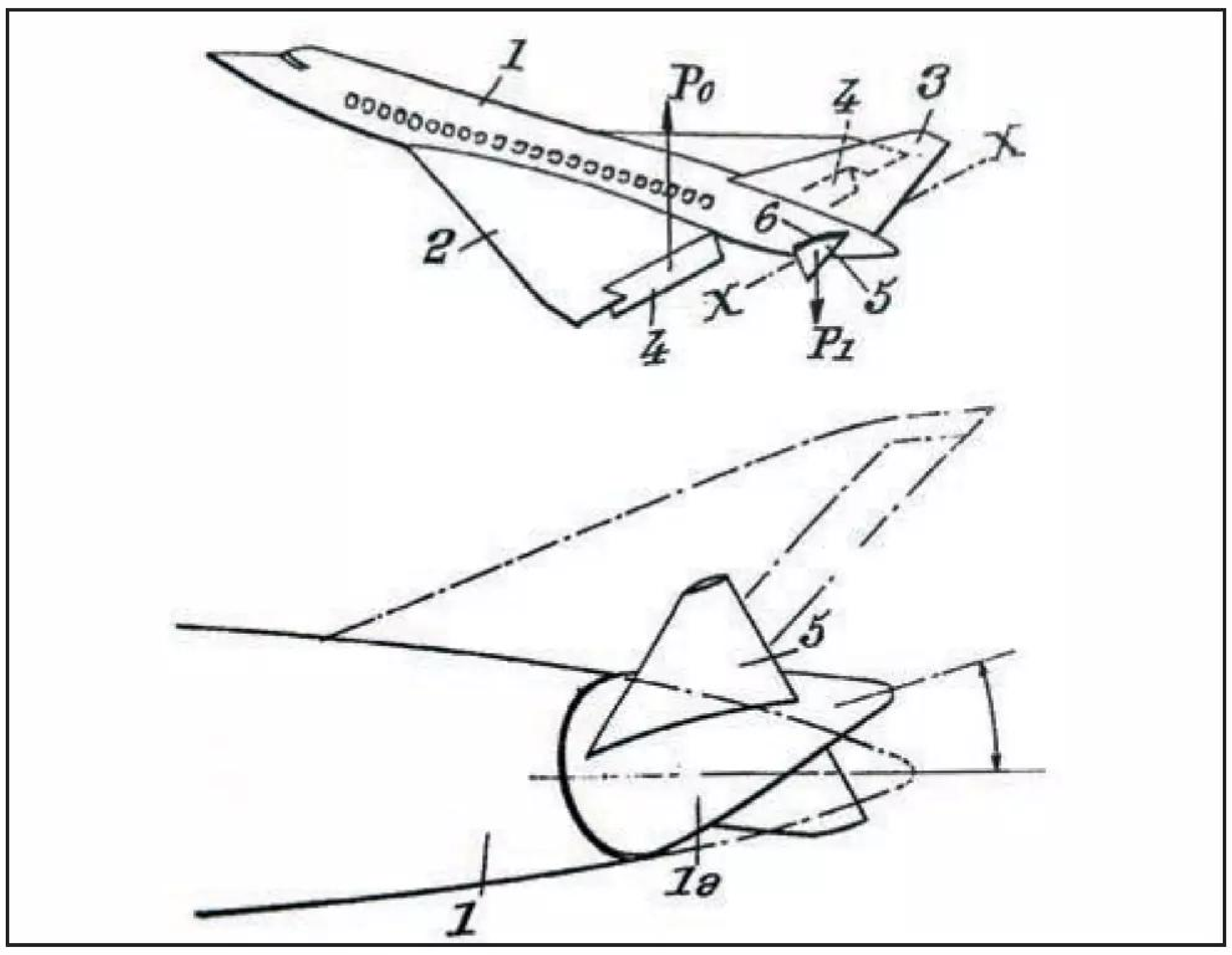
SNECMA designed a ‘Super Atar’ turbojet specifically for the Mach 3 SST programme. *Safran, GDA – Espace Patrimoine, Fonds SNECMA*


— 80 PASSAGERS - 3.000 Km. —

Another three view drawing from 1958 of the early Super Caravelle. This variant is for 80 passengers and a range of 3,000km (1,865 miles). *Sud Aviation via JC Carbonel*


— 100 PASSAGERS - 2.000 Km —

The 100 passenger version of this aircraft would have had a range of 2,000km (1,245 miles). *Sud Aviation via JC Carbonel*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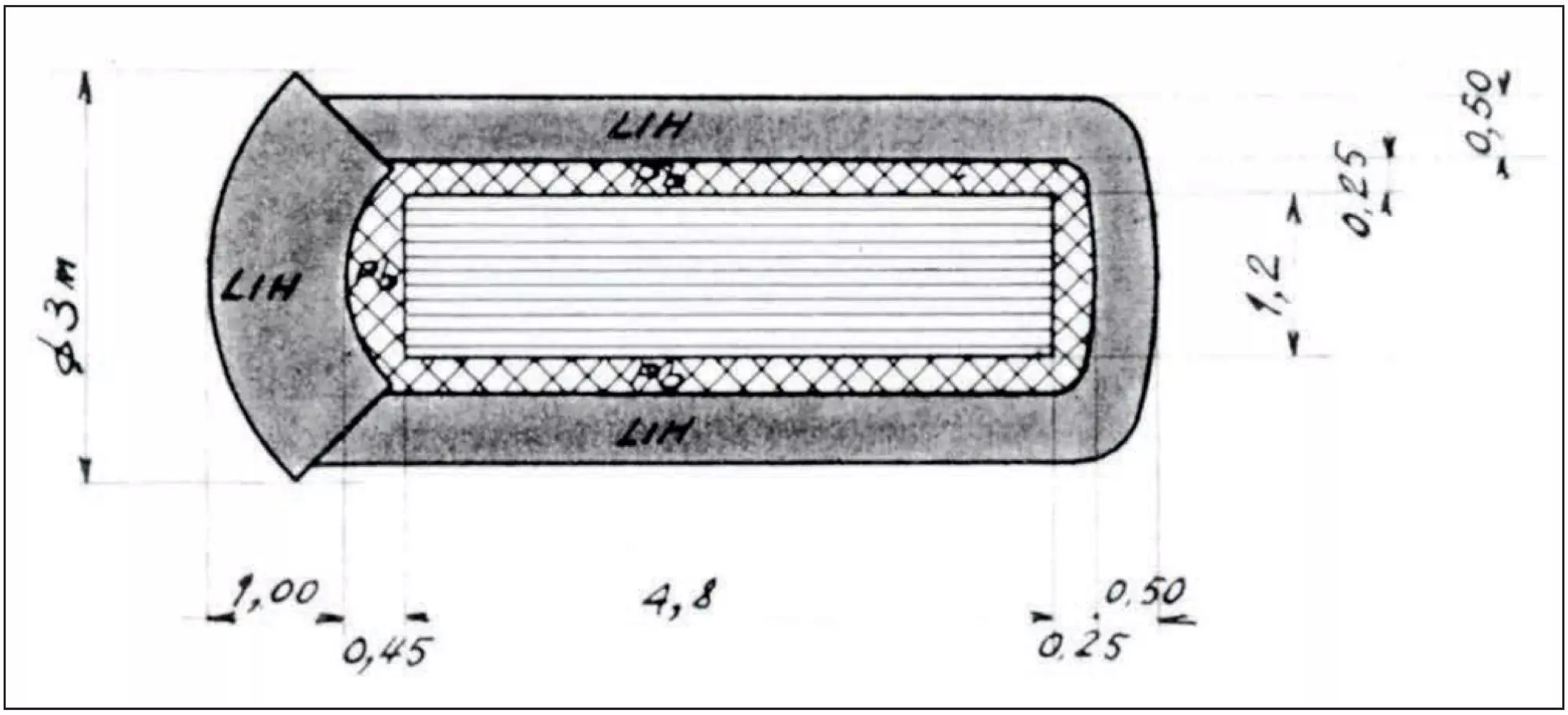
It is well known that Concorde would eventually get a moving droop nose. What is not so well known is that ONERA suggested fitting a moving tail and end fuselage to the Super Caravelle, as shown by this patent. *ONERA Patent, via JC Carbonel*



Drawing showing the atomic pile in the 'nuclear' Super Caravelle with the lead 'armour' required to protect the passengers and crew from its radiation. *Sud Aviation via JC Carbonel*

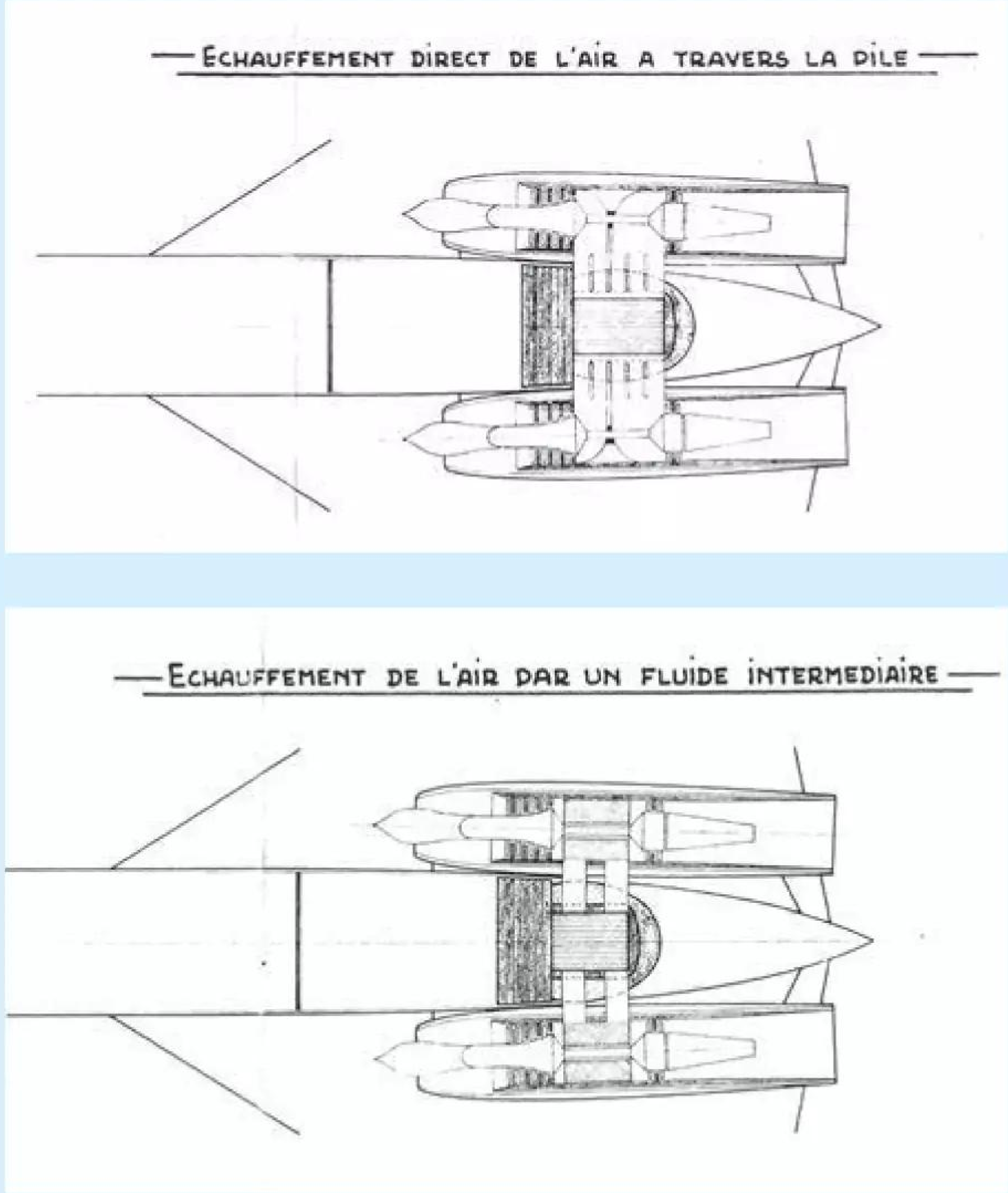
On being told about the SST study, Héreil turned to another design office led by Lucien Servanty, which specialised in high-speed (mostly military) aircraft. Servanty had just concluded work on the supersonic SO 9050 Trident II interceptor and had therefore acquired some unique experience in designing supersonic aircraft. Héreil told Servanty to produce a worthy successor to the Caravelle but insisted that there should be a family likeness between the Caravelle and the new SST. Indeed, the design was to be called Super Caravelle to emphasize this continuity.

This resulted initially in the 60-passenger X-225 of early 1958. The target speed was Mach 1.6 to Mach 2, where kinetic heating would not be an issue. The X-225 had a delta wing with a 54° leading edge sweep and five turbojets – four in twin pods at the rear of the fuselage (as in the Caravelle) with the fifth at the base of the fin. Range was 3,000km (1,865 miles) and the X-225 would have a take-off weight of 125 tons, including 65 tons of fuel. Engine type was not specified but 17,500-20,000lb (77.8-88.9kN) thrust was needed with reheat deemed necessary for take-off. The X-225 was probably the work of the SE 210's designers: André Vautier and Pierre Satre.

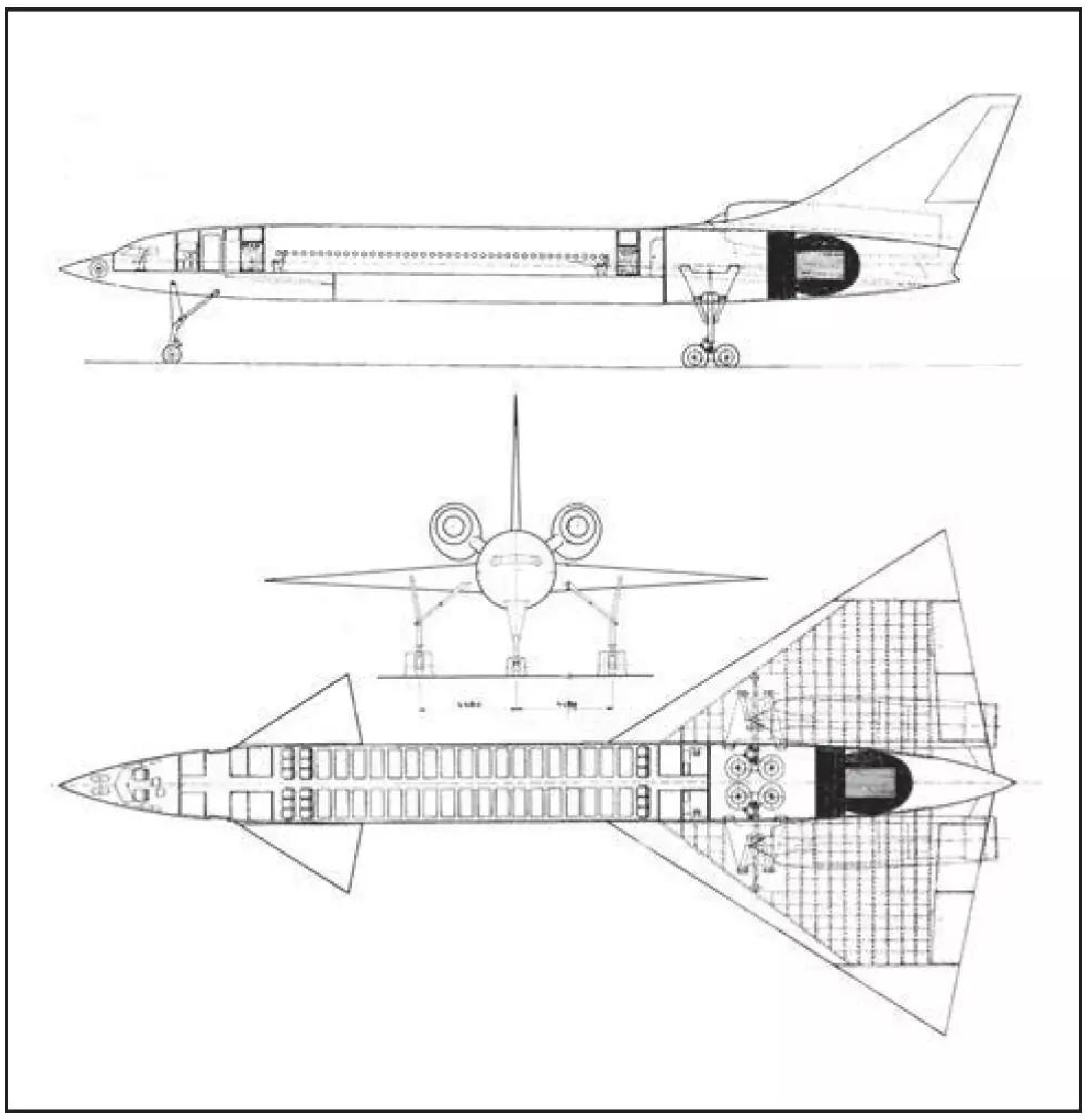
The requirement for a familial Caravelle likeness was largely forgotten, being present only in the shape of the tail, access stairs under the rear fuselage, and in the position of the turbojets. It was considered that a variable lift surface in front of the centre of gravity was needed to balance the aircraft – hence the canards.

SUD NUCLEAR SUPER CARAVELLE

In March 1958 Sud issued a brochure which described a Super Caravelle 'Version à propulsion nucléaire' – a nuclear-powered variant! This brochure was aimed only at giving "a first contact with the idea", but concluded that "this basic study showed no obvious impossibilities against the design


ECHAUFFEMENT DIRECT DE L'AIR A TRAVERS LA PILE
ECHAUFFEMENT DE L'AIR PAR UN FLUIDE INTERMEDIAIRE

Sud drew both direct-flow and indirect-flow propulsion systems for its nuclear Super Caravelle. Yet the design team was perfectly aware that the direct-flow solution was more trouble than it was worth. Even the indirect-flow system would have posed problems that were difficult to solve, notably in terms of maintenance. *Sud Aviation via JC Carbonel*

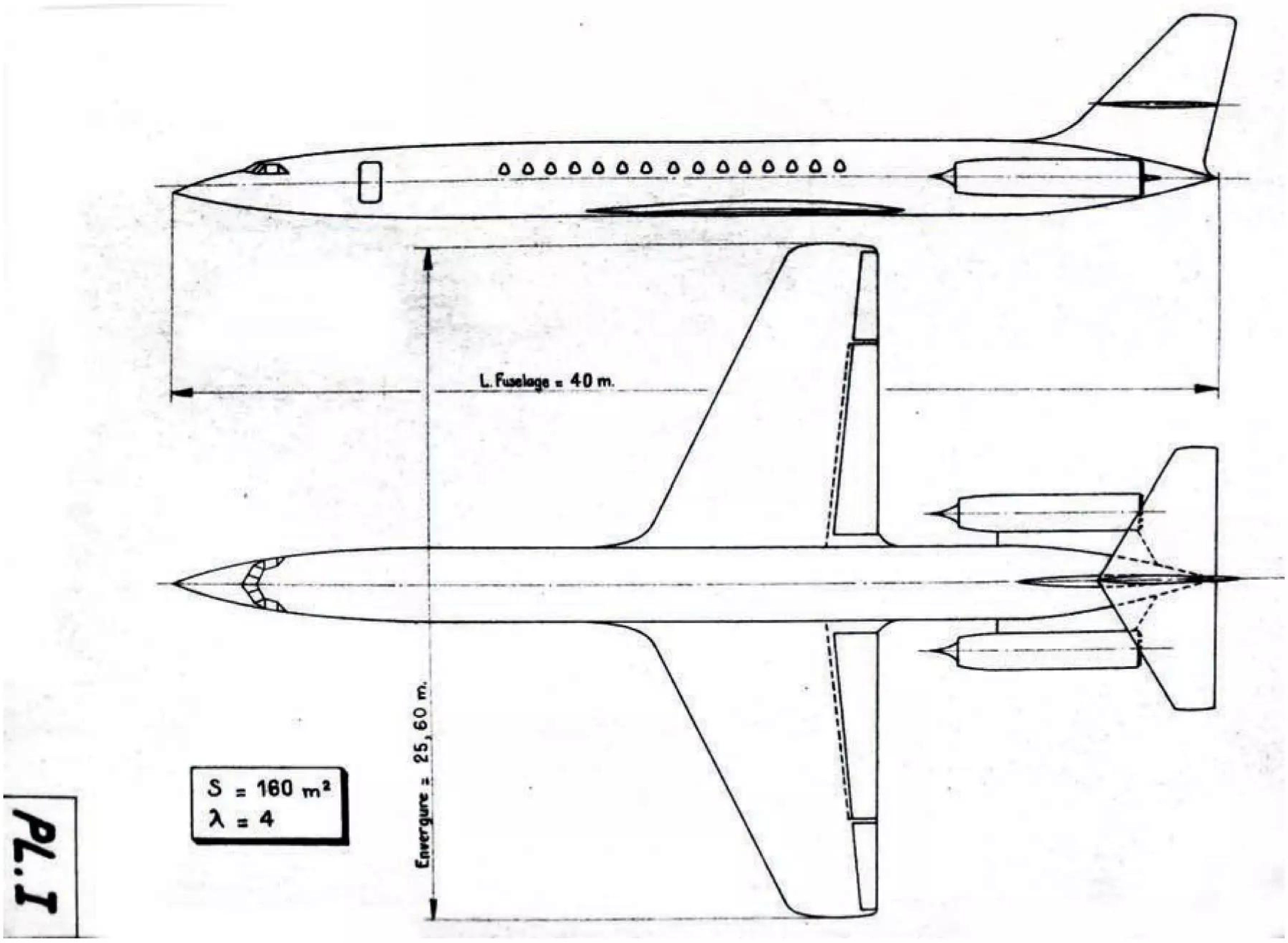


Three view drawing of the Super Caravelle with nuclear propulsion. The general appearance is similar to the 1958 Super Caravelle but note the huge engine pods and beefed-up undercarriage, the main gears having 4-wheels. Sud Aviation via JC Carbonel

of a nuclear-powered airliner". The earliest problem to be encountered was the question of reactor cooling. It was feared that the heat exchange would become too difficult because the aircraft's outer skin would become hotter with speed, so the design team settled on Mach 1.8 as the project reference speed. However, it confirmed that "the problem of heat exchange will still require a lot of technological effort".

Range, considering the limited consumption of uranium fuel, was defined as "nearly unlimited" so it was advised that a nuclear Super Caravelle should be used on flights longer than 3,000km (1,865 miles). The propulsion system would be small and lightweight relative to the massive fuel load normally carried by long-range airliners and the brochure acknowledged a temptation to "increase the payload of the aircraft considerably". But reason prevailed due to the difficulty in designing the circuits linking the reactor to the engines and the desire to avoid extra complexity.

So in the end the base Super Caravelle design was only moderately enlarged with passenger capacity increased to 120 and payload to 15,000kg (33,070lb). Both fuselage and wings were increased in size but the wing structure was simplified. General layout was kept the same as the base project but the passengers were moved to the front, away



This is a 'foil': a three-view drawing of an aircraft which was never projected – a conventional airframe Super Caravelle which Sud's Bureau d'Études thought was not viable. *Sud Aviation* from the reactor and engine system at the rear. Low fuel consumption also eased the problem of weight balancing. Two shields were to be installed, one around the reactor itself and a lighter one just behind the cabin. The brochure declared that residual radiation would not bring any adverse health effects – “it would need 130 flight hours for the most exposed passenger to receive a dose of radiation equivalent to a single radio examination”.

Both open- and closed-circuit powerplants were considered. Liquid bismuth was selected as the exchange fluid for the closed circuit system, which would emit less radiation and thus require less shielding, reducing weight. Starting the engines, after activating the reactor, could be done conventionally.

With an open-circuit engine, the turbojet would eject radioactive air on starting. One potential solution to this was starting each turbojet by injecting kerosene in front of the turbine. No provision for a conventional fuel tank was ever mentioned in the design of this machine, something which could be avoided with a closed-circuit system, but the use of a liquid metal like bismuth would require a pre-heating circuit.

Shutting down the hot reactor quickly was a problem which could not be readily solved and other difficulties included regulating engine thrust, control at altitude and protecting the rubber undercarriage wheels from radiation-induced deterioration.

A further study for a nuclear-powered VTOL SST was made using a ‘quick neutrons’ reactor (a closed-circuit system) but this was not pursued owing to the problems relating to the number, positioning and installation of the lift jets.

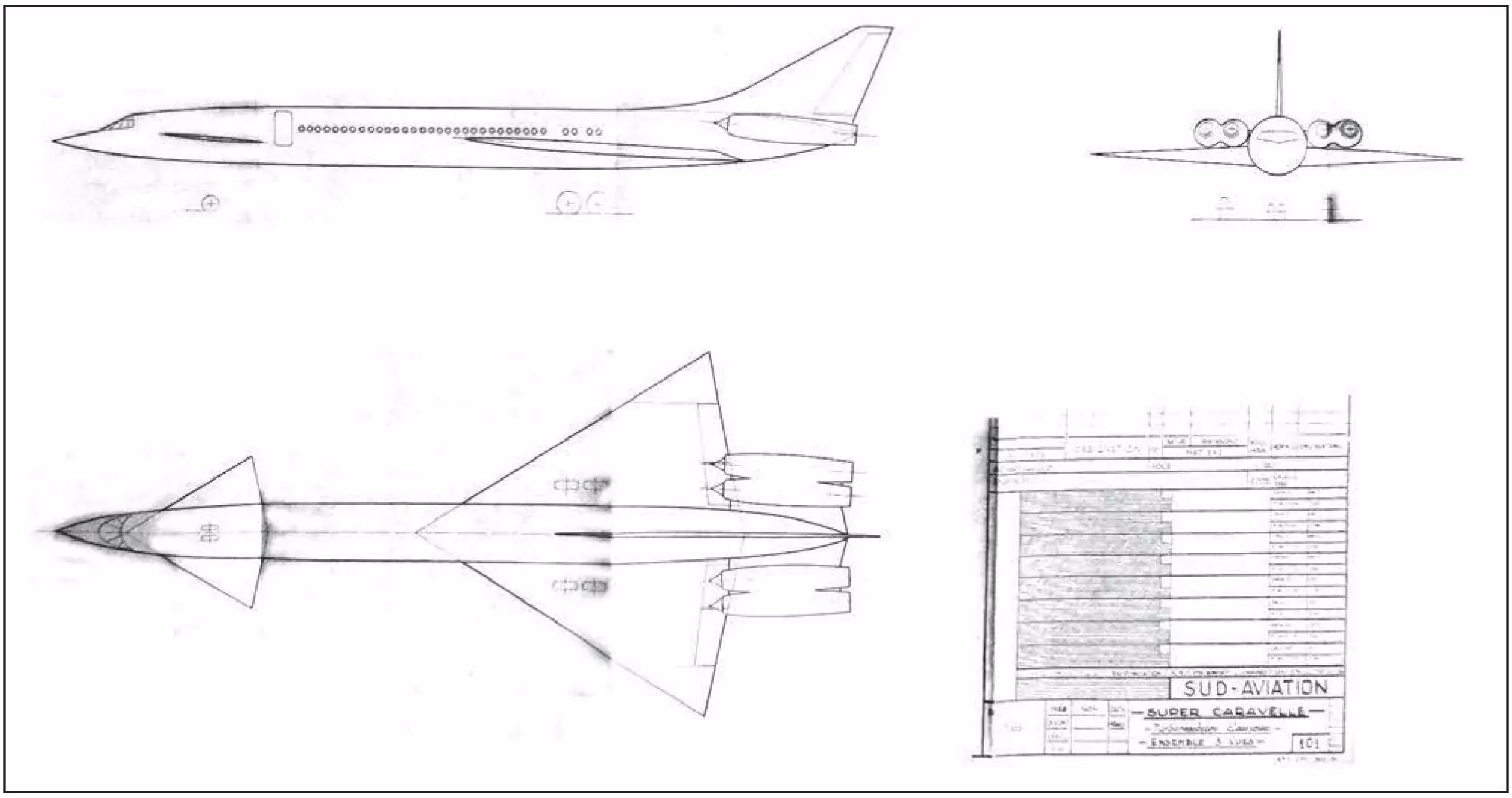
On 4 May 1959 the STAé, ONERA and the manufacturers met to discuss the interest in, and possibilities for, pursuing research on a supersonic transport aircraft. The resulting report concluded that “it is not unreasonable to begin today to study a supersonic transport aircraft which will enter service between 1965 and 1970” but it also recognised no suitable French engine jet existed to power it.

Servanty was promoted to chief of the Sud Aviation Bureau d’Études in July and left his Courbevoie team for Toulouse. He put Gilbert Cormery in charge of the SST study but still visited each week to check on the progress with the SST project.

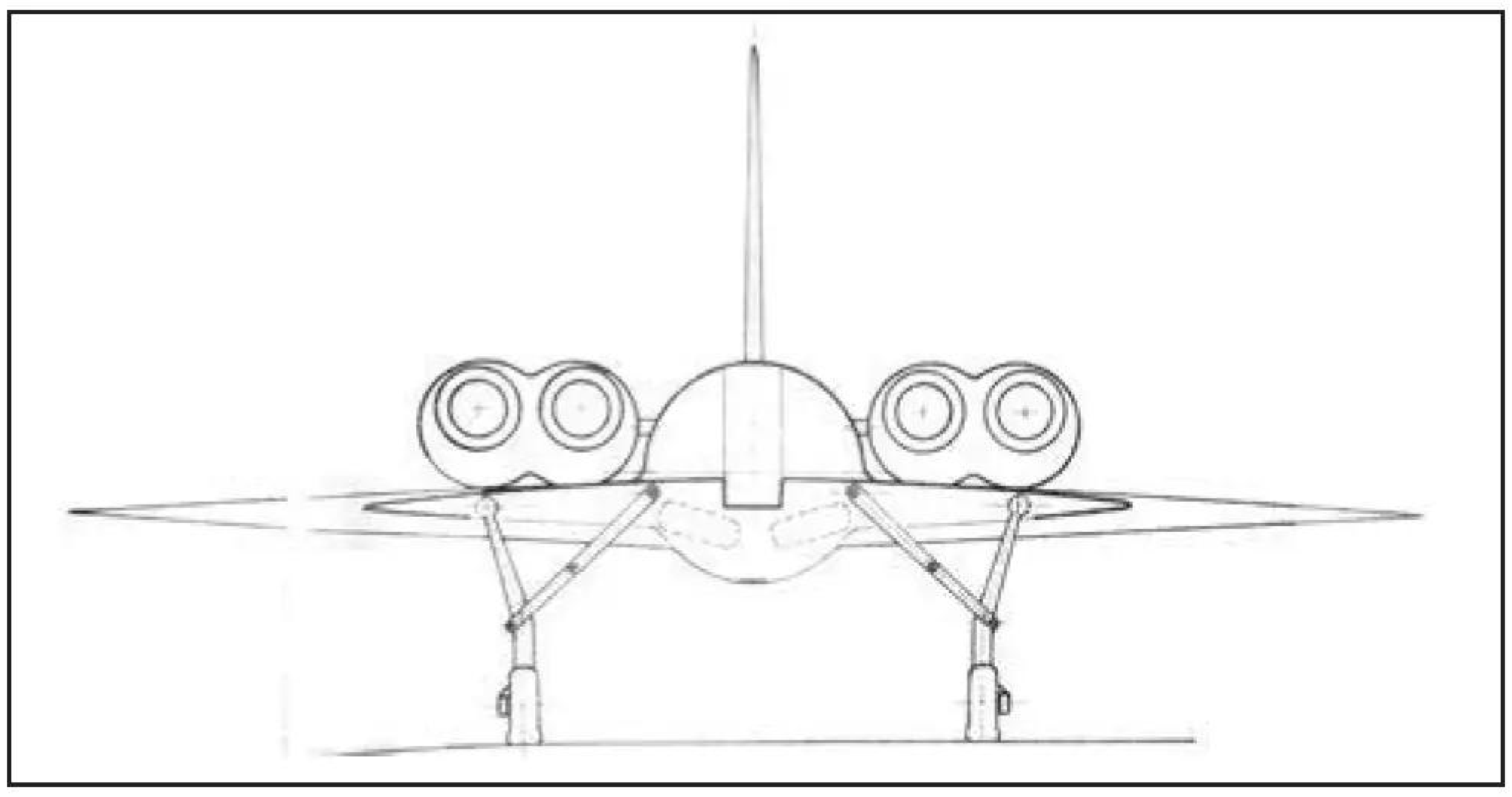
THE ‘CLASSIC FORMULA’

The Bureau d’Études issued a note on 12 October 1959 an SST directly extrapolated from the Caravelle’s “classic formula” with straight low aspect ratio and low relative thickness wings and the engines in rear fuselage pods. This note pointed out how easy it was to do the calculations because the “aerodynamic characteristics and the structural weights are easy to obtain without specific calibration”. Fuselage lengths ranging from 33-40m (108-131ft) were studied and although a four-engine variant was suggested, all the calculations referred to a twin-engine design. In both cases the reference turbojet was the Rolls-Royce RB.151.

However, it was found that such an aircraft would be too expensive and concluded that “there is no point of looking for a solution to the SST problem through a classic formula as shown, considering the prohibitive costs obtained. It is therefore necessary to look at new aerodynamic shapes to obtain… operating costs of the order of those already observed on current airliners.”



A full three view drawing of the early-1958 Super Caravelle. *Sud Aviation via JC Carbonel*



End view of the 1958 Super Caravelle. Modellers will appreciate the drawing has the landing gear rendered with 'weighted' tyres. *Sud Aviation via JC Carbonel*

VTOL STUDY

On 21 September 1959 Sud issued a report bring together all of the publications identified so far that had looked at a civilian SST. 'Study 599' pointed out that while the US manufacturers had opted for Mach 3, the European manufacturers were aiming at only Mach 2. One of the major findings of the various pieces of research was the necessity to integrate the engines into the airframe design; another point was the selection of the canard arrangement to allow for better longitudinal stability and a better weight arrangement within the airframe.

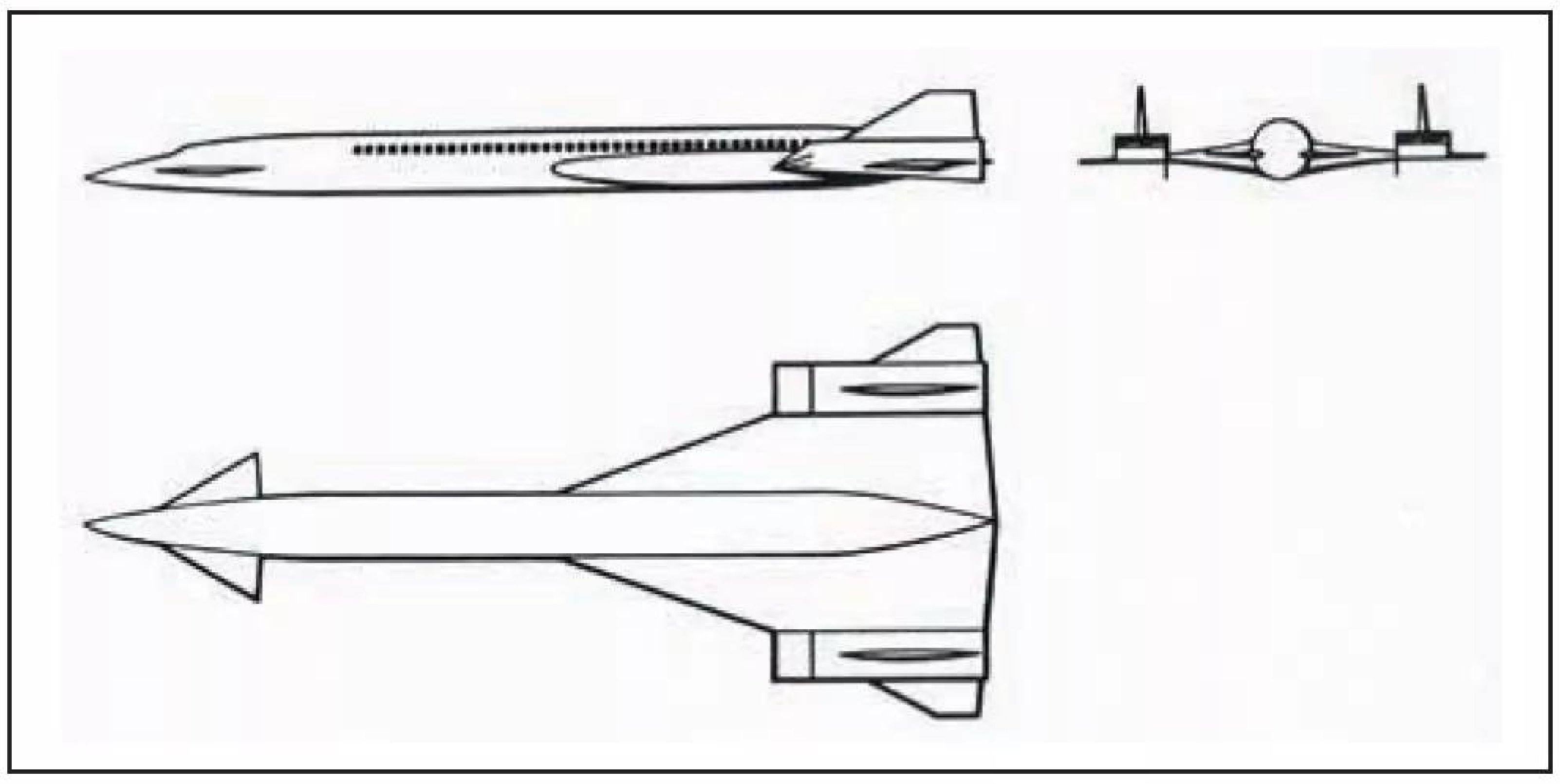
The calculations the firm had made so far for different configurations – twin turbojets, four turbojets and six turbojets for a conventional take-off aircraft plus a VTOL study – were collected in a note on 15 October. Among the variables was number of passengers (60 or 80 with either 1,200kg/2,645lb or 1,600kg/3,525lb of luggage) and the aerodynamic lift to drag ratio. It was estimated that creating the aircraft would take 7 years and that it would fly 3,000 hours yearly.

The quoted powerplant was either the RB.158 or RB.160, and the lift engines were to be RB.162s. Speed was set at Mach 2.2 with 3,000km (1,865 miles) range. The note added that comparisons between conventional and VTOL variants were being made, with the VTOL configuration apparently looking less expensive.

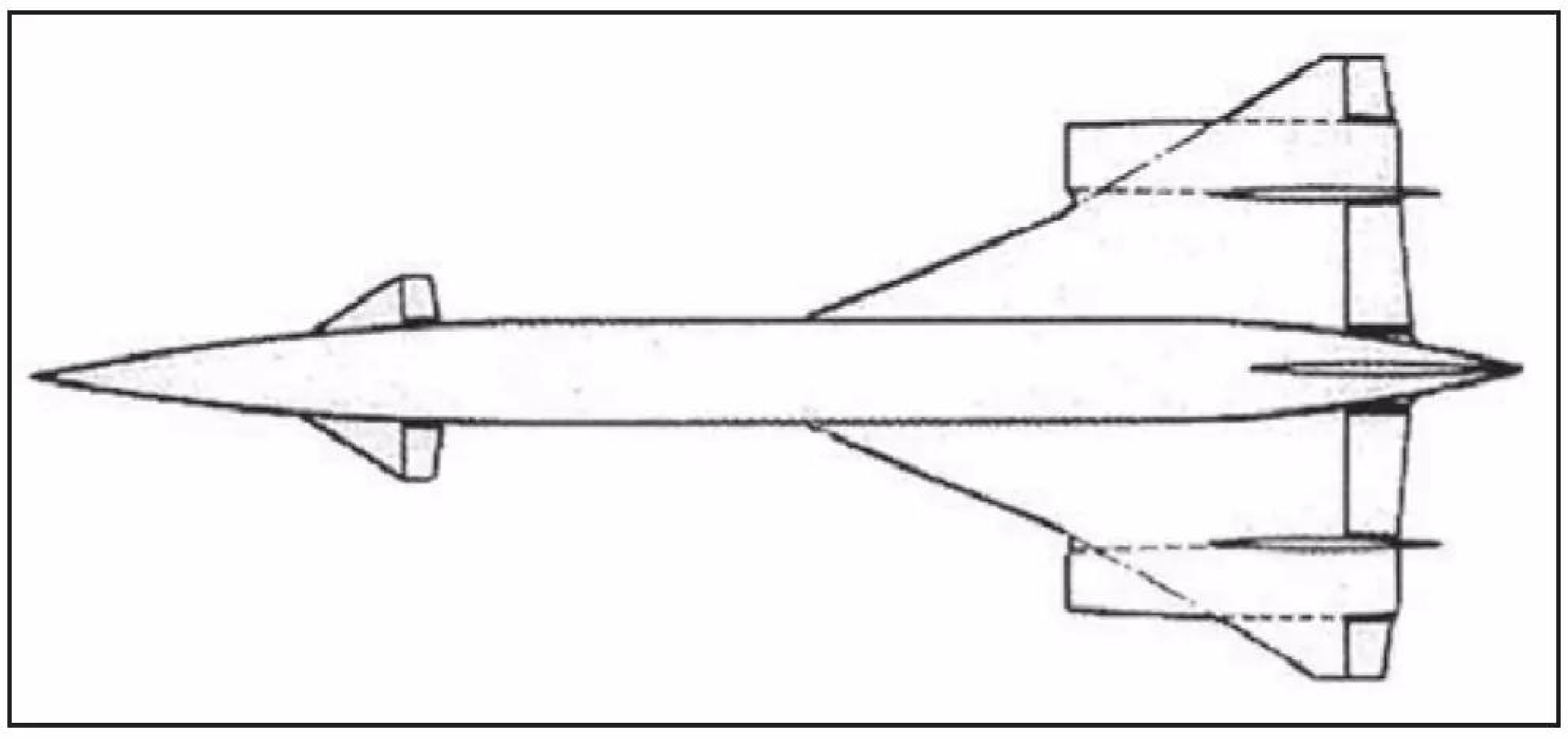
The VTOL project was Servanty's pet idea and, although no specific brochure has been found to date, it was mentioned in the nuclear SST brochure. Cormery remembered "we even tackled the study of a VTOL variant. Vertical take-off was on paper a very attractive solution and Professor Griffith was a strong proponent of it in the UK. [However,] although the fuel reserves for re-routing and loitering could be dispensed with almost completely, the complexity of fitting 28 lift engines [into the airframe] led us to postpone this adventure indefinitely".

THE PURE DELTA

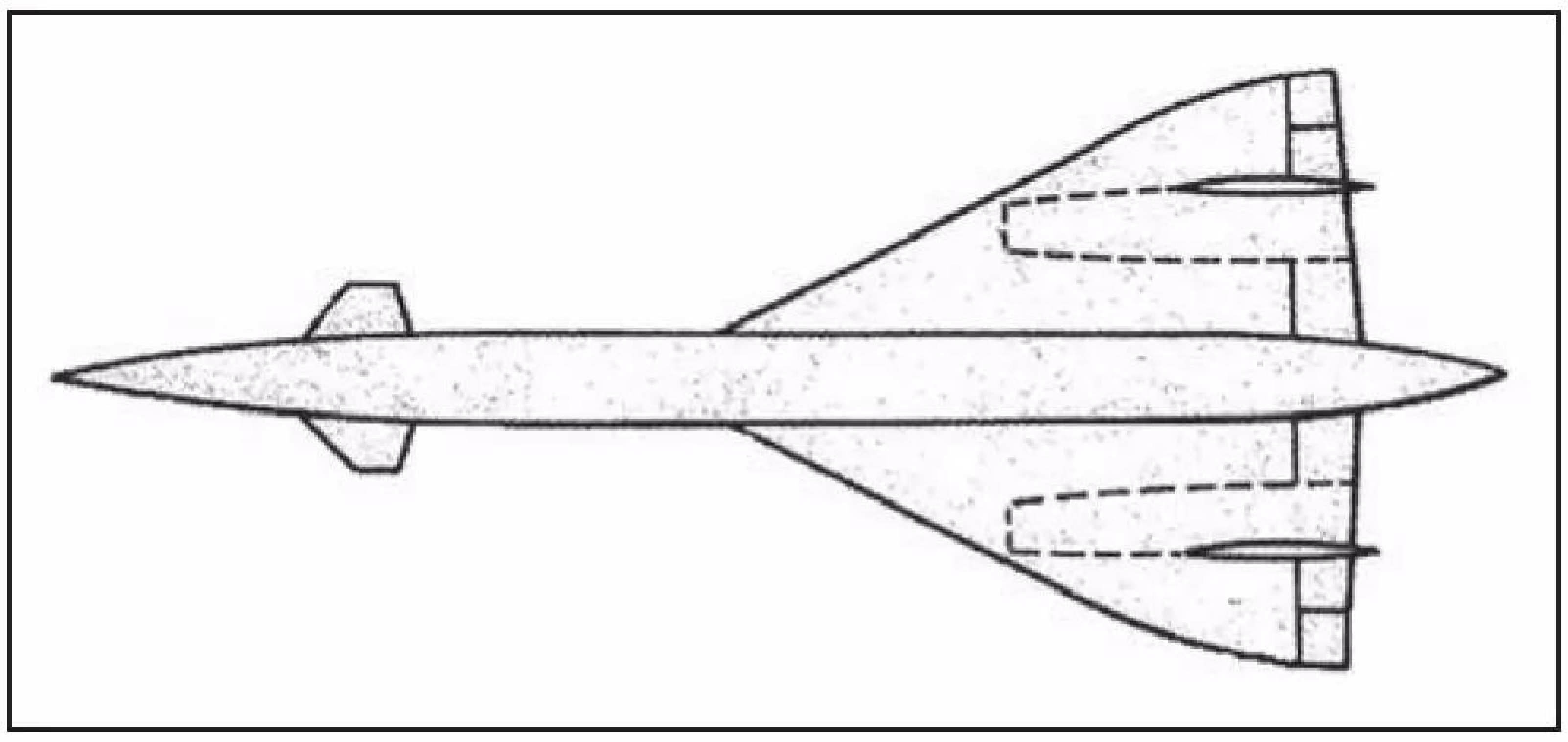
ONERA was officially tasked by STAé to study the optimal aerodynamic features of a civilian supersonic transport in 1958 and this work suggested that the optimum shape was



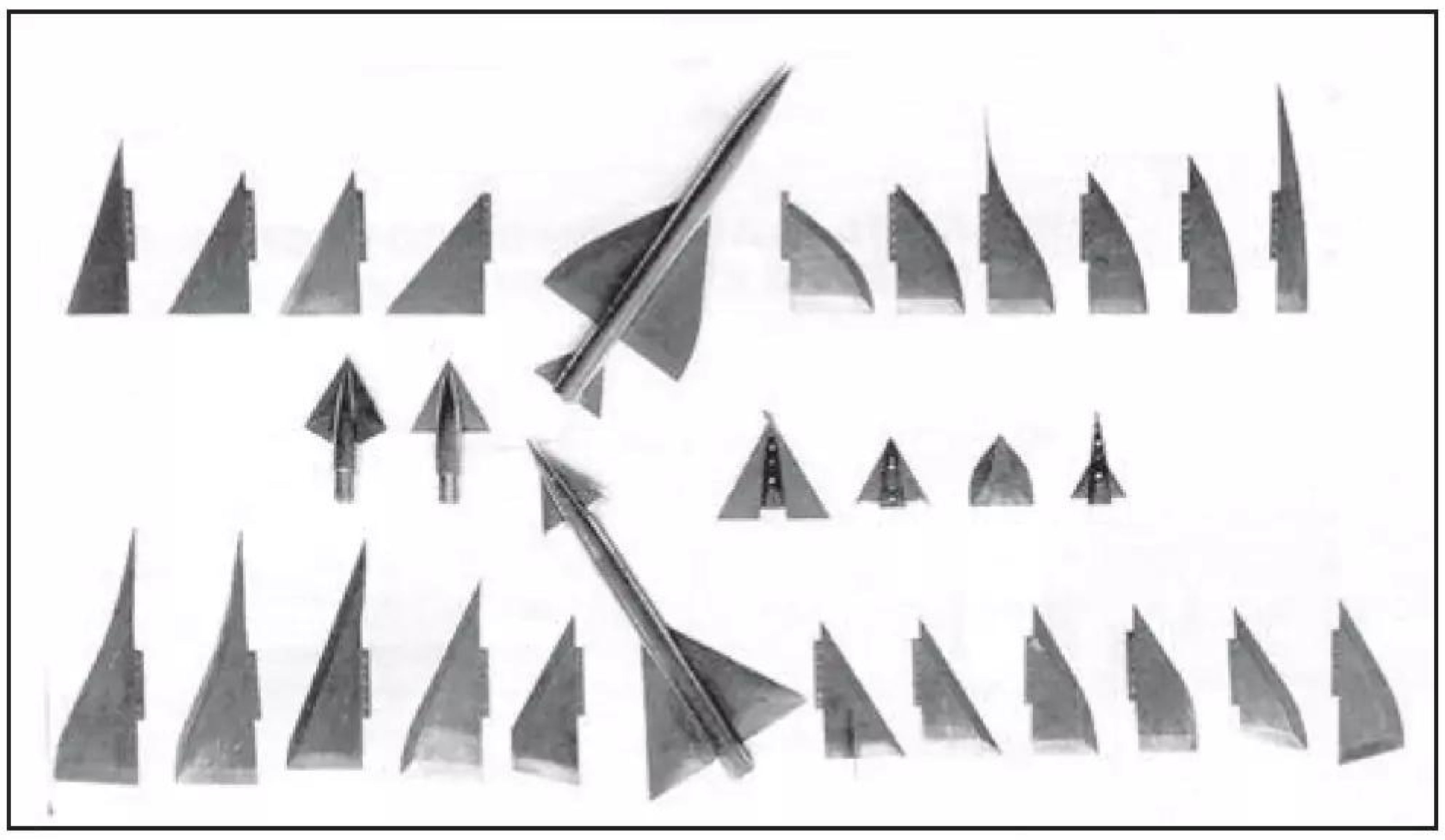
A rare drawing showing the transition between the early canard version of the Super Caravelle with diamond wings and the later delta and ogee wings variants. Note that, as recounted in the text, versions with two outer fins as shown here and outer fins plus larger main wings were assessed... without success. *Copyright AIRBUS/AIRITAGE/ D.R via JC Carbonel*



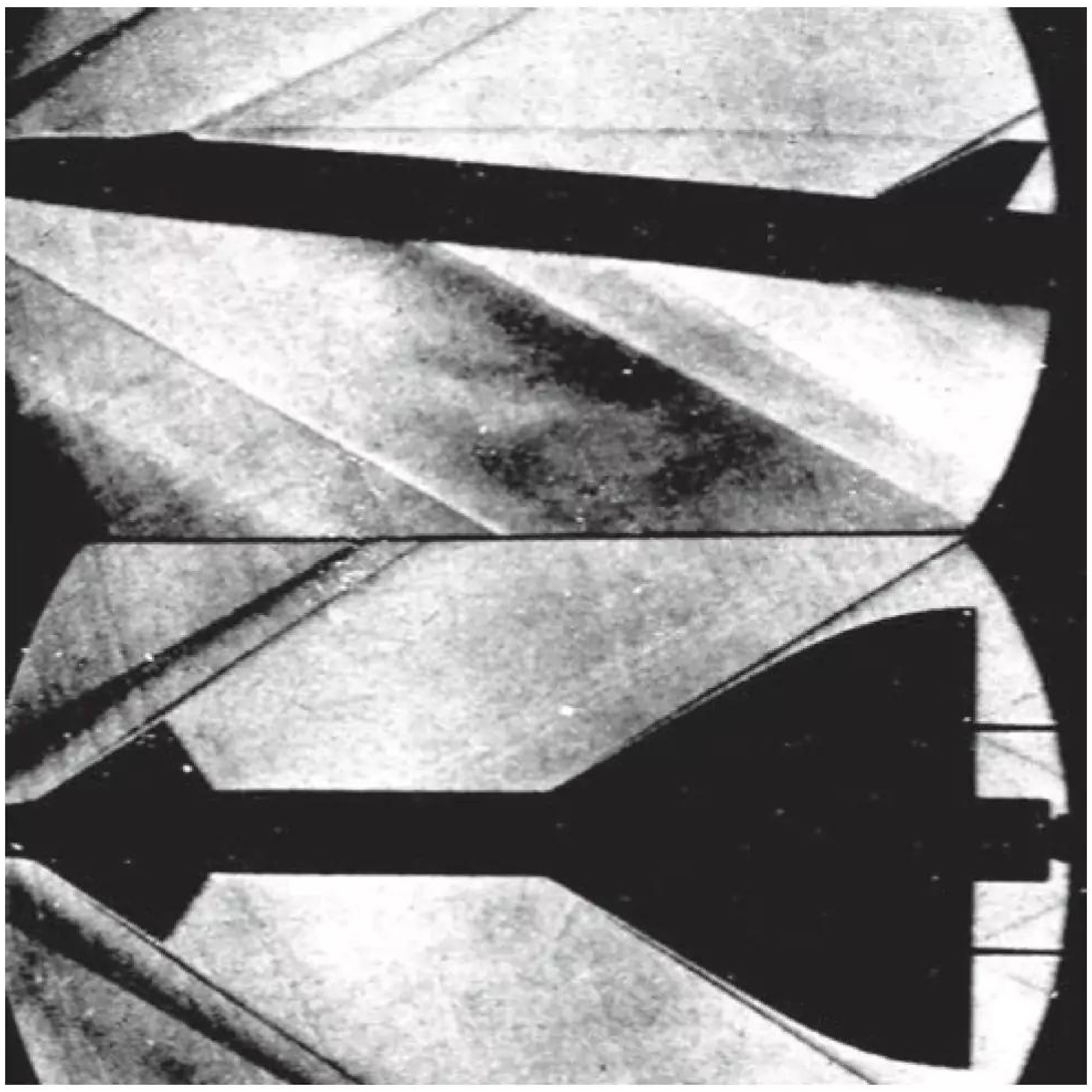
A representation of the Sud Aviation Super Caravelle design as it had reached in (probably) late 1959. *JC Carbonel*



Similar view showing the Super Caravelle as it looked in 1960. *JC Carbonel*



A selection of SST configurations which were tested by ONERA in its wind tunnels. Notable is the diversity of canard surfaces. *ONERA via JC Carbonel*



Photograph of a Transport Civil Supersonique model being tested in the wind tunnel. This picture comes from a 1962 ONERA report and illustrates a stage in which the TCS still sports canards, yet the wing is evolving from the early diamond shape to a gothic shape. *ONERA via JC Carbonel*

a canard configuration with a high-sweep delta wing – the canard was thought to present no serious aerodynamic interference with the vertical fin(s) at high incident angles. This result encouraged Sud's Bureau d'Études in its approach and also influenced Dassault and Nord Aviation heavily in their forthcoming studies.

Meanwhile, in the early part of 1959, Sud had made a change to its SST design which saw the wing switched to more of a pure delta with the engine pods moved beneath the wing. However, when a model of this new design was subjected to wind tunnel testing it revealed flaws.

Cormery later explained "in 1959... the configuration we had reached [had numerous defects]: the air intakes went in front of the leading edge, the point where the fuselage diameter began to slim down was the same as the point where the wings were becoming smaller (bad for the area rule!) and we needed three fins: a real nightmare! We had begun with a single central fin but the first low speed wind tunnel test revealed a strong lateral instability caused by the vortex generated by the canard surfaces.

"We therefore opted for two fins but they required so much separation that their leading edge intercepted the vortex generated by the apex of the wing, which generated a violent and terminal pitch-up phenomenon. We only found salvation in a three-fin design which was barely functional".

Sud believed a viable configuration had been found but it was so dependant on precise parameters that it would be next to impossible to turn the aerodynamic model into a full-size aircraft.

MEETING THE BRITISH

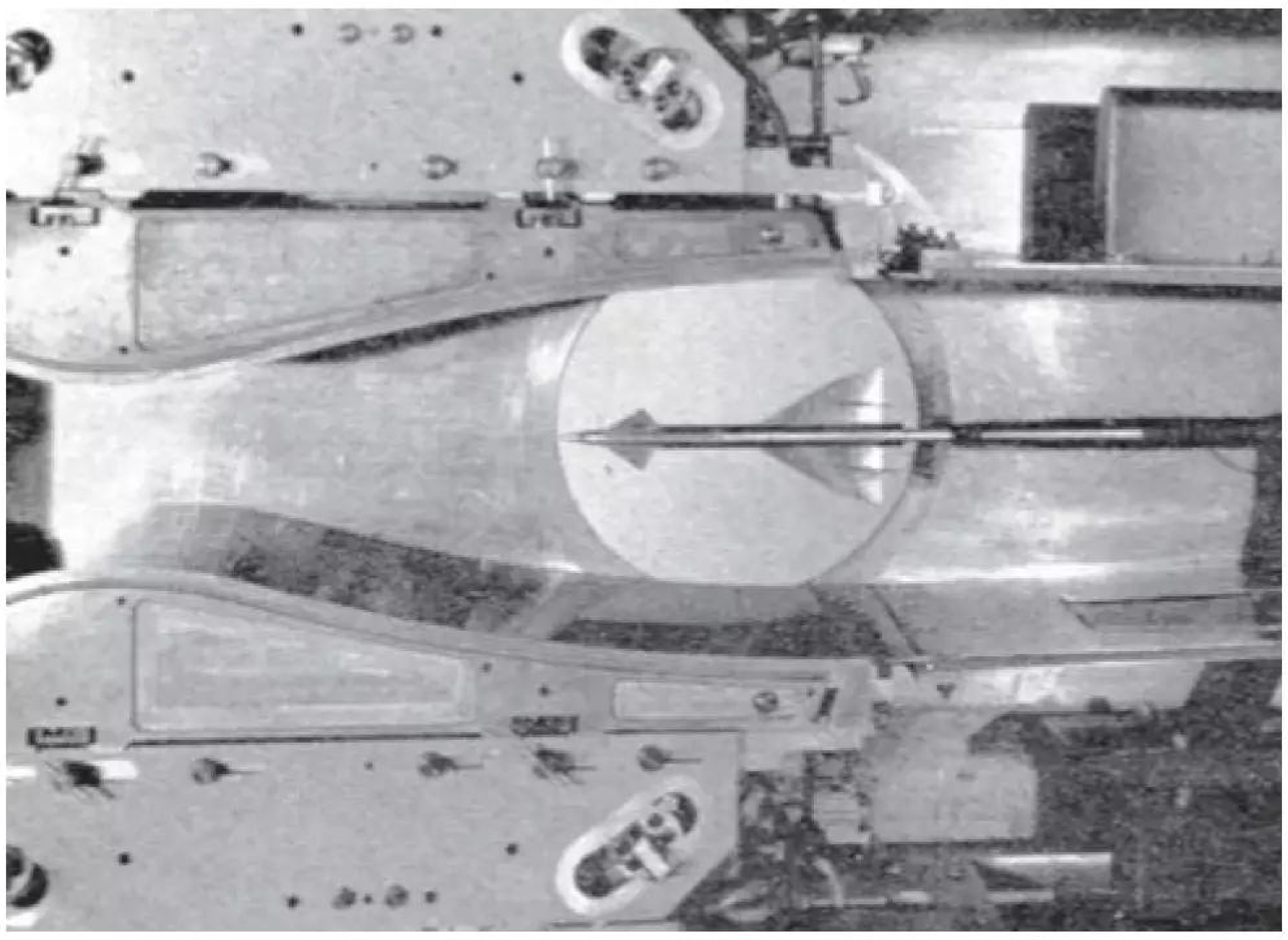
During August 1959 some tentative contacts were made by Aubrey Jones of Britain's MoS to DTIA director Ingénieur Général Louis Bonte. At this stage the French SST business was still handled by the military side of the Air Ministry; later it would fall under the Direction Générale de l'Aviation Civile (the General Directorate for Civilian Aviation). Then in October a meeting was held between a British delegation led by Walter Cawood and a French group led by I.G. Gerardin – see Chapter 5 for full details.

In short, the British outlined their work up to this point and explained that the SST was beyond the financial capacity of the UK alone. However, they were aiming for a long-range 150-passenger Mach 2 SST, with the market for such an aircraft expected to be 150-300 units in 1970. The French, however, were focused on the medium range type – for which the British thought there was no market.

In a report on the meeting for the DTIA, Ingénieur Chef Lagarde declared the project too expensive at an estimated cost of 35-45 billion francs. He thought that the British had "recently lost the long-range subsonic battle and are tackling the supersonic battle with even less assets than the first [subsonic] one". He added that Air France, while state controlled, had greater latitude than BOAC in the selection of the aircraft it needed and that it would be interesting to know the position of the other European airlines before committing to any project. Finally he suggested devoting more resources to developing the Caravelle in full and to forgo the whole supersonic affair or at least stay with the medium range SST. He did suggest, however, that a marketing study was required to clarify the debate.

SUD, NORD AND DASSAULT

On 15 December 1959, Ingénieur Général Bonte asked Sud, Nord and Dassault to participate in a feasibility study for a 60-80 passenger Mach 2 or Mach 3 SST with 3,500km



Another photo of a Mach 2 TCS being tested in the S2 wind-tunnel at Chalais-Meudon. This is also taken from a 1962 ONERA report. *ONERA via JC Carbonel*

(2,175 miles) range. It had to take off from a 2,500m (8,200ft) runway without any form of reheat but VTOL variants were specifically forbidden. Mach 1 could not be exceeded at heights of less than 11,000m (36,090ft) and fuel reserve was to be 5%, which would allow for 30 minutes loitering at 6,000m (19,685ft) and/or re-routing to an airfield 500km (311 miles) away.

The responses were to be submitted by the end of 1960, but in fact they took longer. Dassault's brochure was dated March 1961, Nord's was March/April 1961 and Sud, after an initial detailed reply in April 1961, offering its Super Caravelle IIID version in November 1961. This last design was modified to incorporate a transatlantic capability (Paris-New York) which was the first recognition that the original French thinking towards a medium range aircraft for intra-Europe or trans-Mediterranean routes had been a mistake.

MEETING THE BRITISH (AGAIN)

On 9 December 1959, Senate vice-president André Méric had written in the minutes of the French Senate sessions: "The British, who appreciate the quality of our technicians better than we do, have proposed for us to pool our effort to create a supersonic transport. I believe no agreement was reached ... [but] Mr Minister you must demand the construction not of a medium range machine but of a transatlantic aircraft which, thanks to Sud Aviation's technical leadership, could be competitive on international and flag routes."

A second meeting between the French and British took place on 10 February 1960. The French delegation outlined the design study request issued to Sud, Nord and Dassault nearly two months earlier and both sides discussed experimental flight testing – the British would test steel structures using the Bristol 188 and slender delta wings with the Handley-Page HP.115 and Fairey Delta 2.

The French would carry out noise measurement tests using a Mach 2 Dassault Mirage IV. On the question of the involvement of other countries, all delegates excluded any contact with US manufacturers but the French said they were willing to speak to the Germans.

It was concluded that France and Britain should sign a common memorandum to set up SST cooperation, the manufacturers being free to associate as they wished after that; most notably the British engine manufacturers would now be allowed to enter into direct contact with the French aircraft manufacturers. Finally, ONERA and RAE were to pool their research data and in October 1960 a meeting between the two organisations was held at Châtillon near Paris so that they could begin collating their separate research.

GOING NEO-GOTHIC

According to Cormery, on 20 October 1960 the Sud SST design took a sharp turn for the better with the removal of the canards, since these had created a lot of aerodynamic troubles from their interaction with the fins.

British aerodynamicist Dudley Collard, talking in 1999 about the French input into Concorde, declared "wisdom came with the adoption of the so-called "neo-gothic" wing planform. It was decided to test a configuration joining the canard wake physically with the wing by means of a leading edge extension. This was to lead to the Concorde configuration". In *Concorde et son histoire* Cormery added that this really was the time when the way to the solution to the SST problem was perceived: "First we were able to go [back] to the single fin configuration... then with a few adjustments and some good thinking, the true solution became obvious. The first change was to introduce a slight downward curve to the wing leading edge... which led to an improvement in drag. The second was the introduction of the fuel management system, using the leading edge fuel tank connected with another tank at the extreme rear of the fuselage. The final configuration was reached in the spring of 1961."

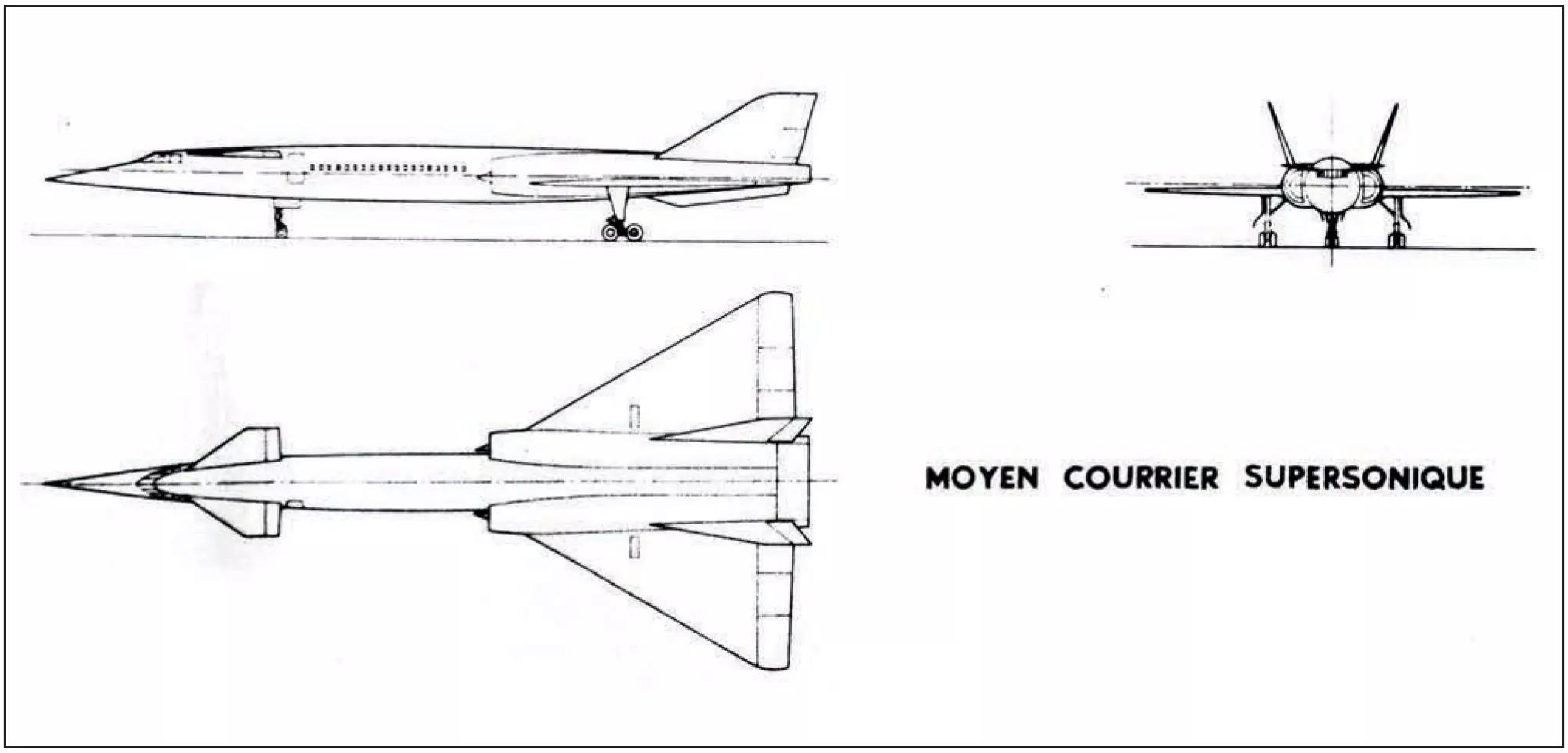
Collard concurs: "The new apex, used as a fuel tank, could be compensated by a rear fuselage balance tank. By using fuel transfer trim drag was eliminated. The advantage of vortex lift, already investigated on slender wing body combinations by ONERA from the early 1950s, was realised. Pitching moment curves were straightened out [and] the fuselage, moved aft compared to the wing (by having no lifting foreplane in cruise), gave a satisfactory area ruled aircraft, so the performance increased significantly."

Satre added at a 1963 conference "to reach our goals, it was necessary to modify the planview of the wing which was no longer a true delta, as the leading edge extension had evolved in the direction of an increase in the sweep of the leading edge, while the extremities of the wing had been cut to reach that so-called gothic shape." What Satre did not say was that the introduction of short strakes along the nose was the true secret: these strakes in fact had a stabilising effect similar to what could be obtained using a canard surface, but without the troubles associated with it. According to Satre the lift-to-drag ratio of the new gothic wing would be good enough in both supersonic and subsonic flight, so the alternative variable geometry wing was unnecessary.

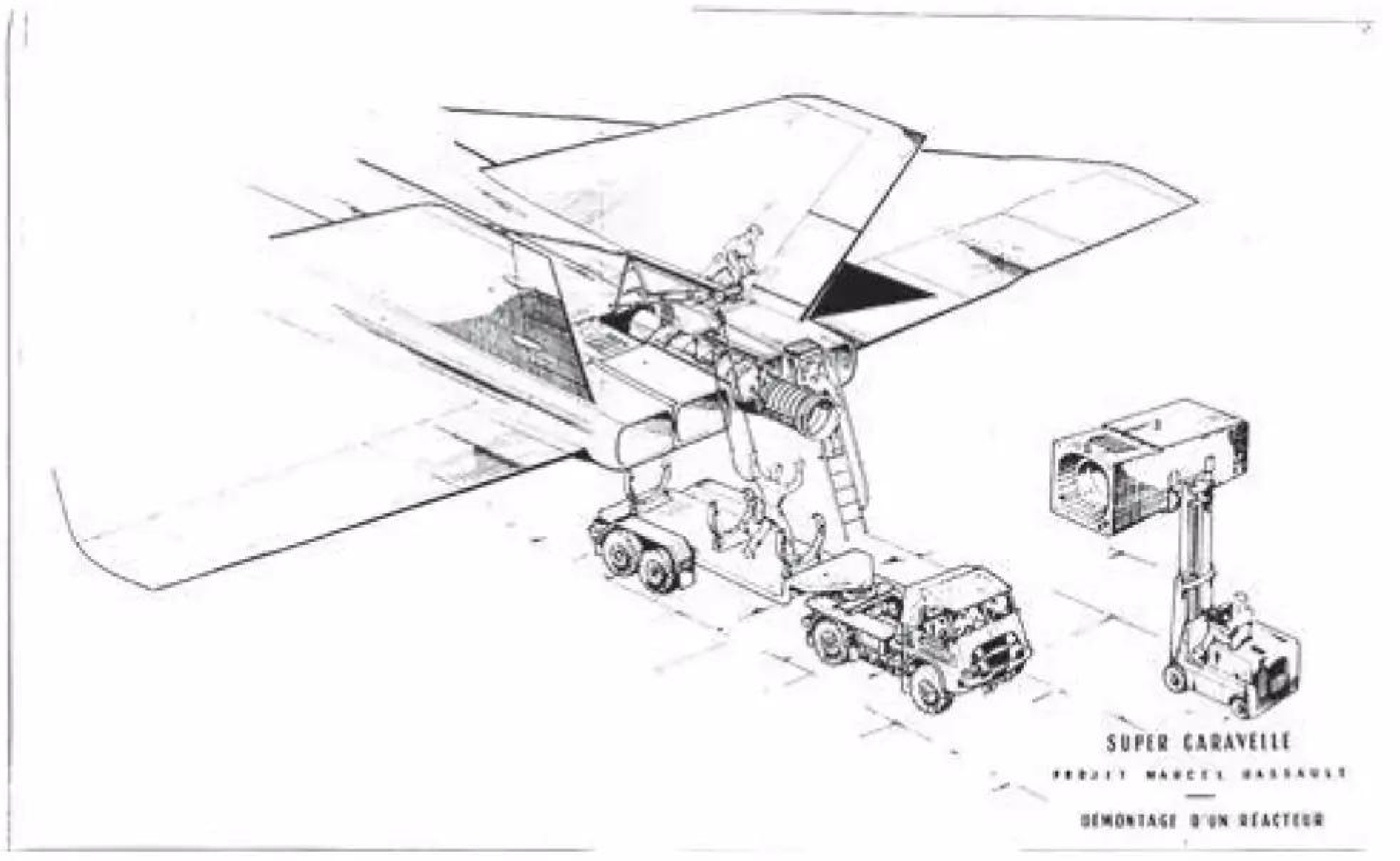
When it came to placing the turbojet nacelles under the wing, Satre said this was done because "on one side this had the benefits of a natural 'over-feed' of the engines, and on the other side the wings benefited from the increase in lift generated by the system of air shocks on the inlets of the engine ducts".

On 30 March 1960 George Héreil and Marcel Dassault met to sign an agreement between their two companies stating that "a programme for a medium range supersonic transport appears realistic, that is, it could lead to a commercial product which would guarantee the profitability of the operation."

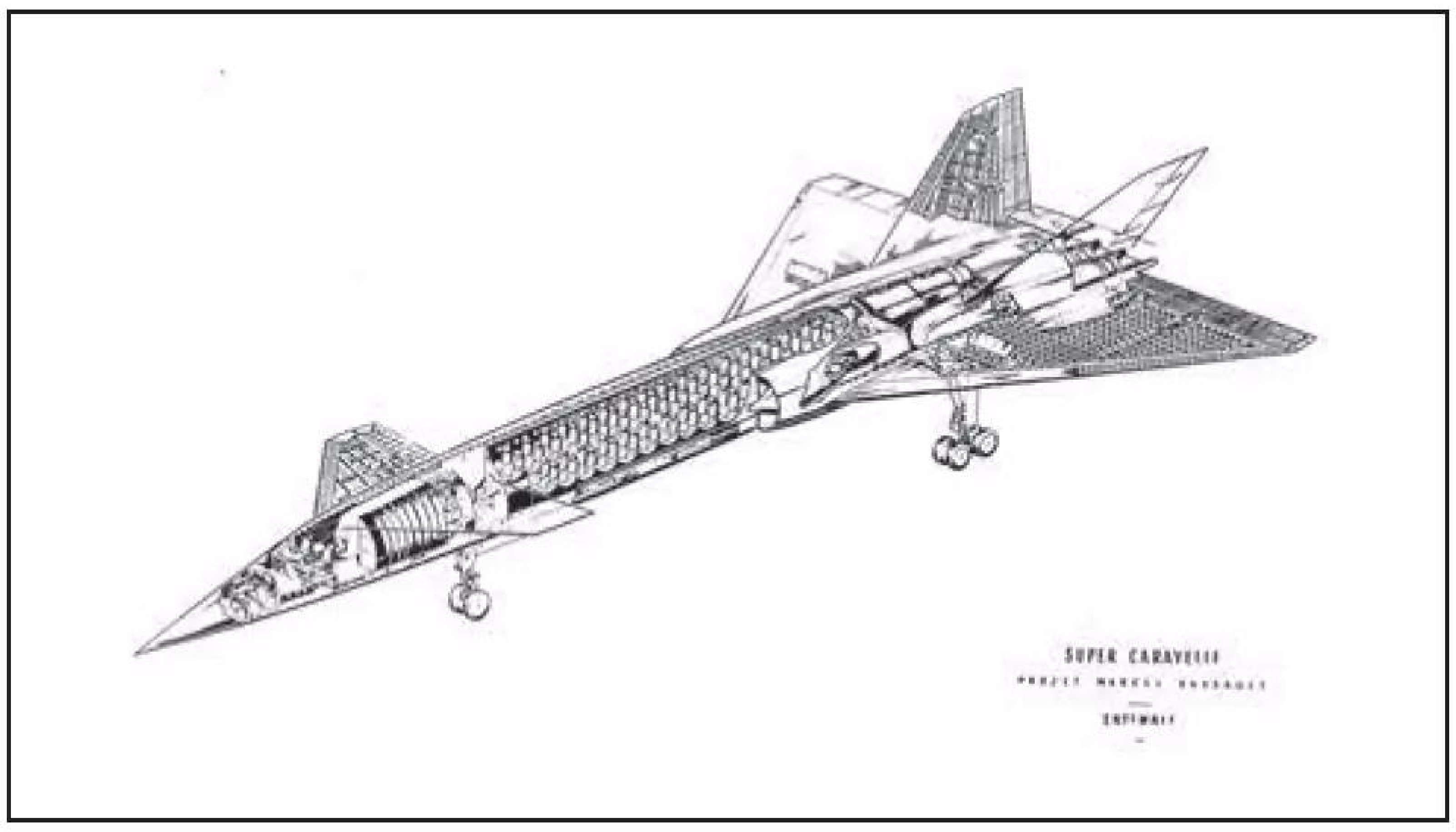
At the XXIV Salon Aéronautique de Paris, opening on 25 May 1961, a large model of the Sud Super Caravelle was unveiled to the public. With this step the French SST


MOYEN COURRIER SUPERSONIQUE

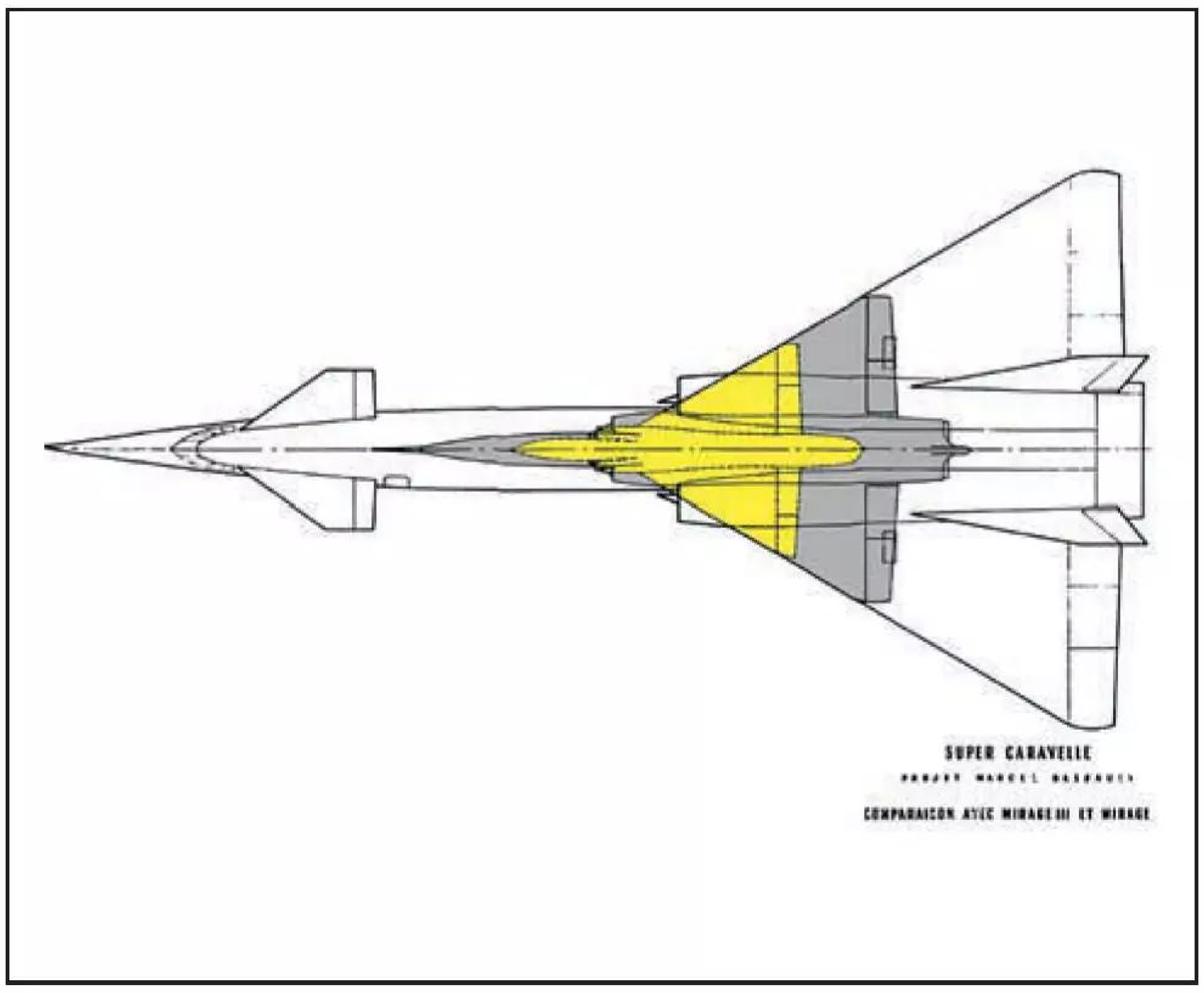
Three view drawing of the Super Caravelle as designed by the Dassault Bureau d'Études. It is dated 8 March 1961. *Dassault*


SUPER CARAVELLE
PROJET MARCEL DASSAULT
DEMONTAGE D'UN REACTEUR

An engine change on the Dassault Super Caravelle as imagined by the firm's engineers. *Dassault*


SUPER CARAVELLE

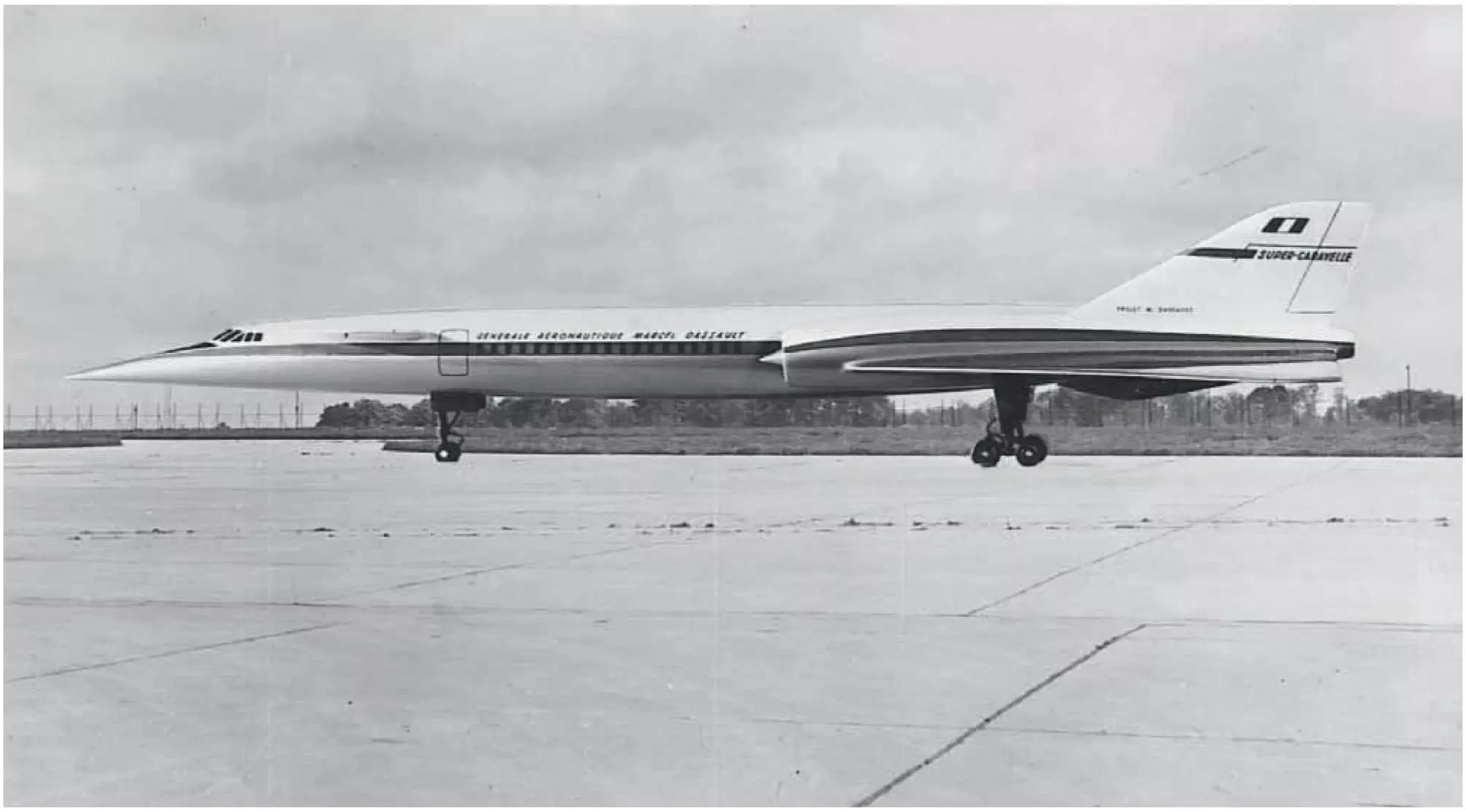
Ghost view of the Dassault Super Caravelle illustrating the inner parts of the aircraft from the navigation radar in the nose, the cockpit, the passenger seats, the fuel tanks and the four turbojets at the rear. *Dassault*


SUPER CARAVELLE
PROJET MARCEL DASSAULT
COMPARAISON AVEC MIRAGE III ET MIRAGE

Comparison between the Dassault Super Caravelle, the firm's Mirage III fighter (yellow) and the Mirage IV bomber (grey). *Dassault*

initiative entered into the public (and political) world, although its existence had been mentioned in the press during the previous months. The agreement between Sud Aviation and Dassault had been played up but it never delivered anything, with the two companies working separately on SST designs.

In September 1961 Air France President Joseph Roos expressed the view that the resources allocated to supersonic aircraft would be better employed in perfecting the Caravelle. However, also at this time the French Minister of Transport Robert Buron and Minister of Armed Forces Pierre Messmer co-signed a letter stating "France must initiate now a major initiative and, in all practicality, technological evolution means it must be supersonic." Conscious of the budgetary constraints they added that "without losing the leadership of the operation, France should be able to restrict its own budgetary load [with European partners] to under 1 billion francs".



Life-like model placed over a real background photograph to show how a Dassault Super Caravelle would have appeared on the tarmac at an airfield. *Dassault Aviation, Direction des Relations Extérieures et de la Communication*

DASSAULT SUPER CARAVELLE

Various tests had been carried out to define the Dassault project of early 1961. A first series had used a large 1/20th scale model for the preliminary definition and another round of tests followed in the M4 wind tunnel at Saint-Cyr using a smaller 1/65th scale model with a modified canard geometry.

The Mach 2 design had a delta wing with 60° of sweep and 3% relative thickness, balance being obtained by a canard and stabilised by two fins attached to the fuselage and set at an angle of 20° from the vertical. A fixed windscreen provided a normal view for the three crew (two pilots and a flight engineer). Capacity was 82 passengers, but depending on the seating arrangement this could vary from 70 to 88.

The four engines were placed in a row at the rear of the fuselage and fed by two side air intakes developed from those designed for the Dassault Mirage IV bomber (with double shock cones). Each intake fed two engines, and each engine had a convergent-divergent nozzle and thrust reverser.

The engine position came from the desire to use the experience gained from the Mirage IV, but it was also advantageous in terms of protection in the case of an engine failure, for keeping the wings 'clean' of any disturbance generated by engine nacelles, and it helped the design to meet the requirements of area rule.

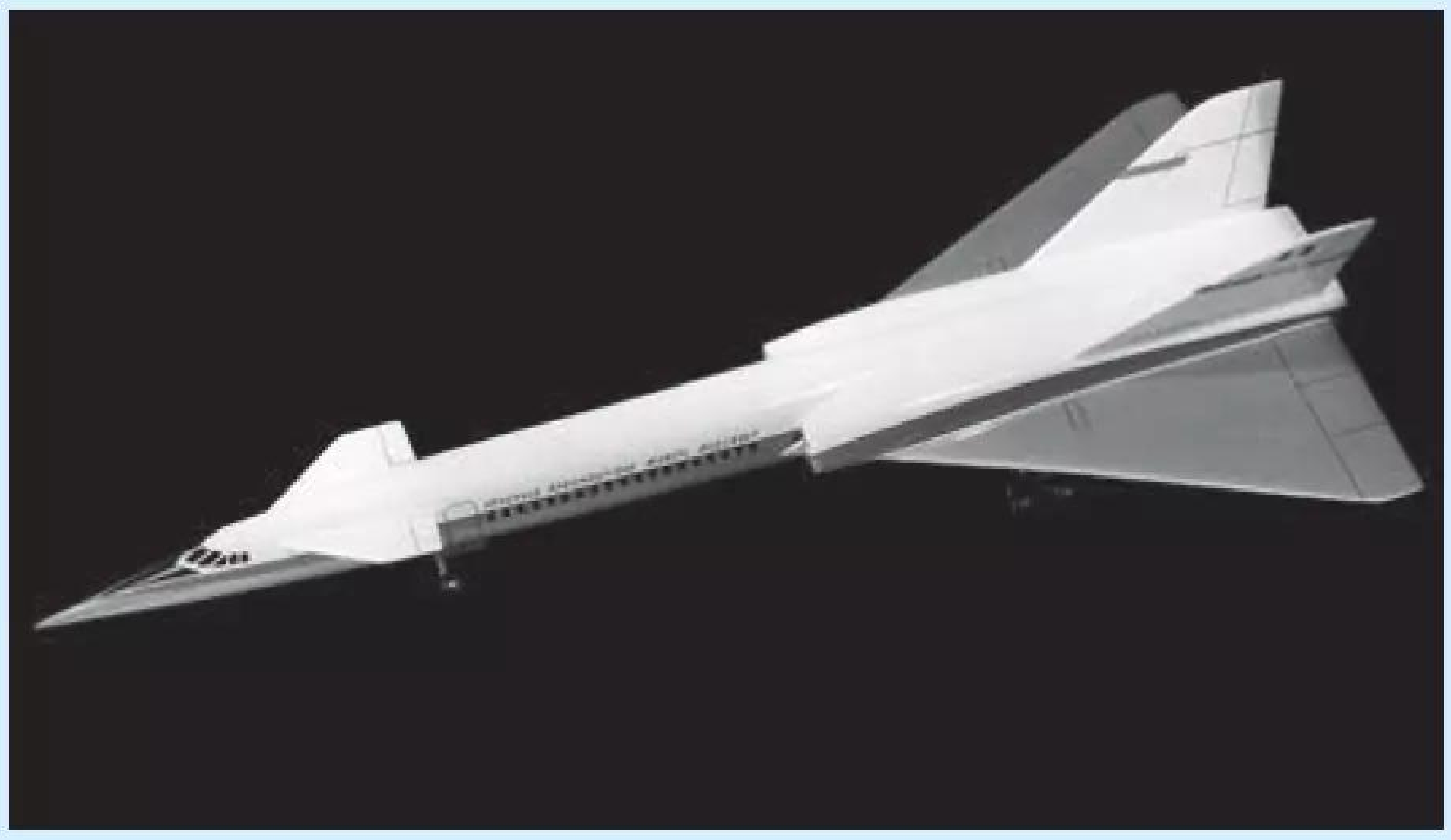
Concerning engine choice, Dassault said: "We have used the engines offered by the Rolls-Royce company for this project, as stipulated by the STAé. We have only checked that the use of the competing engine designed by the Bristol company would not be incompatible with the philosophy of our project."

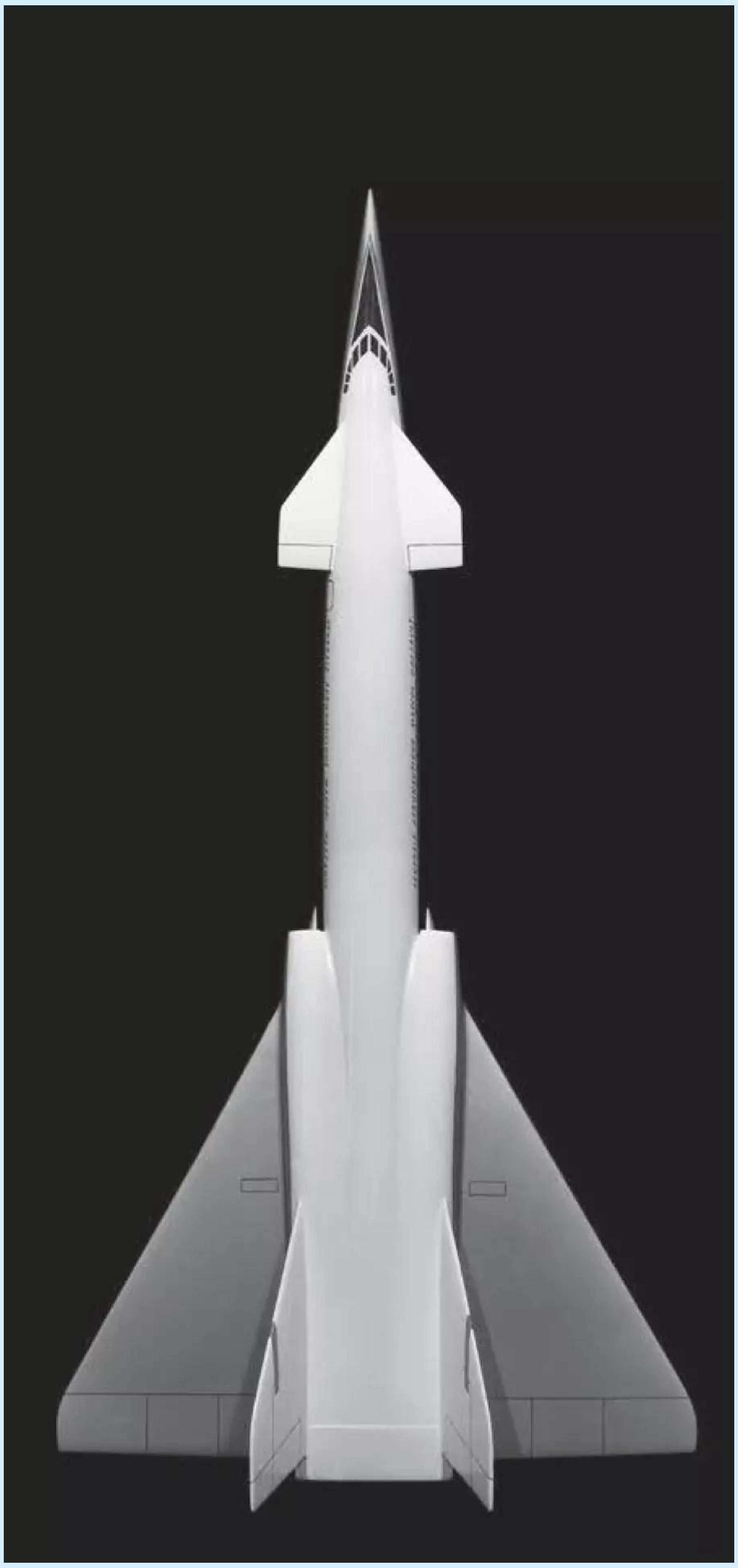
The landing gear was similar in arrangement and operating sequence to the one used by the Mirage IV and provision was made for cooling the landing gear bays during flight.

The canard was a fixed surface with a movable trailing edge to trim the aircraft during the different phases of its flight. Dassault justified its inclusion through the need to trim the aircraft constantly for minimal drag, but it also to give the aircraft the correct pitch angle during its landing phase while providing good visibility for the pilots.

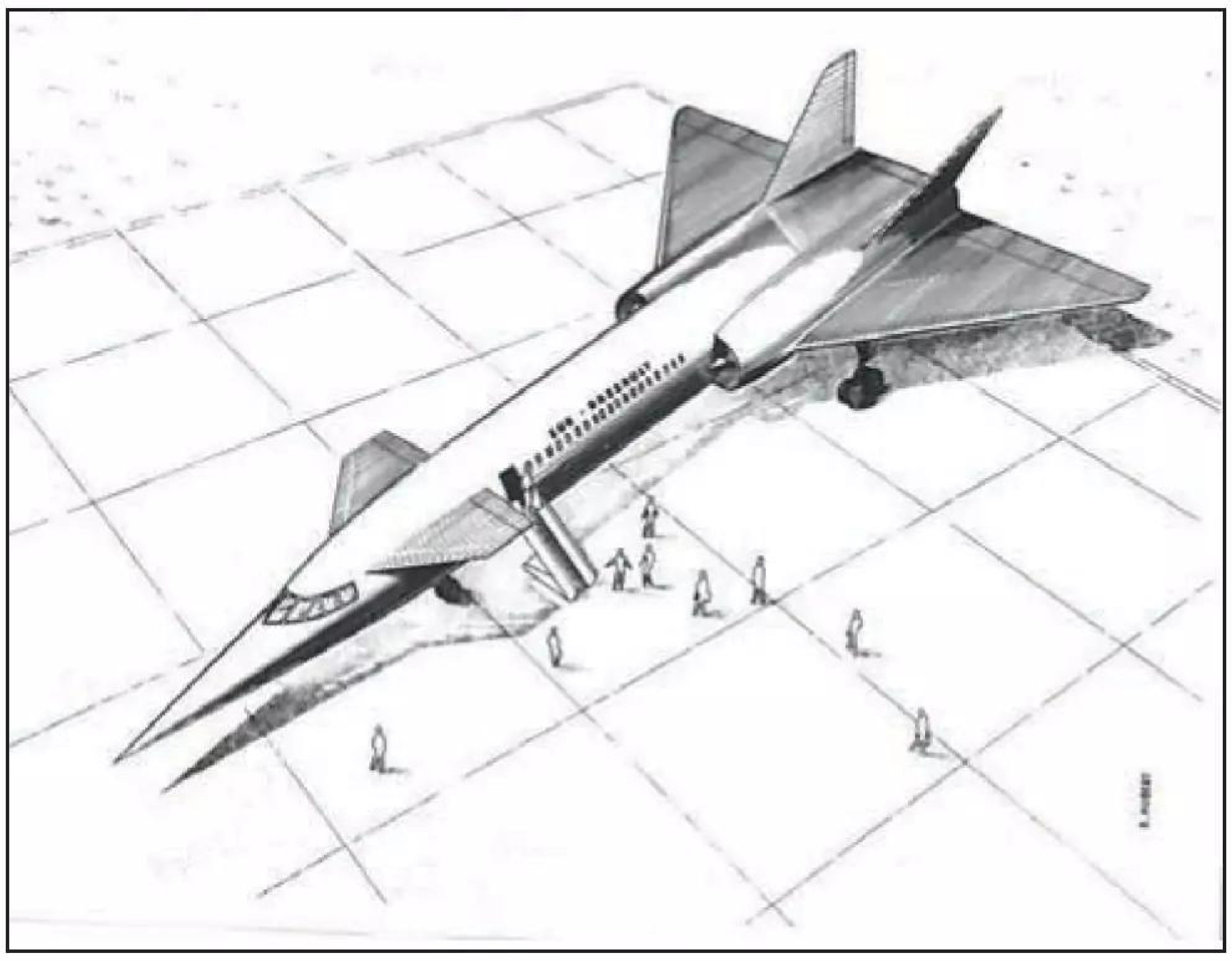
The 3.2m (10ft 6in) diameter fuselage had a split-level arrangement, with the upper section housing the passenger cabin and the lower section the luggage.

Regarding the then ongoing debate about the most suitable range, Dassault had opted for an intermediate solution. While recognising that long range flights (over 4,000km/2,485 miles) only covered 15% of the traffic, Dassault did not limit itself to the 3,500km (2,175 miles) requirement but extended it to 4,000km (2,485 miles) "so that the ability to fly on certain routes would not be closed off". A further study assessed whether the range could be extended by increasing the aircraft's size, and in particular by increasing the wing area, but the results were not convincing.

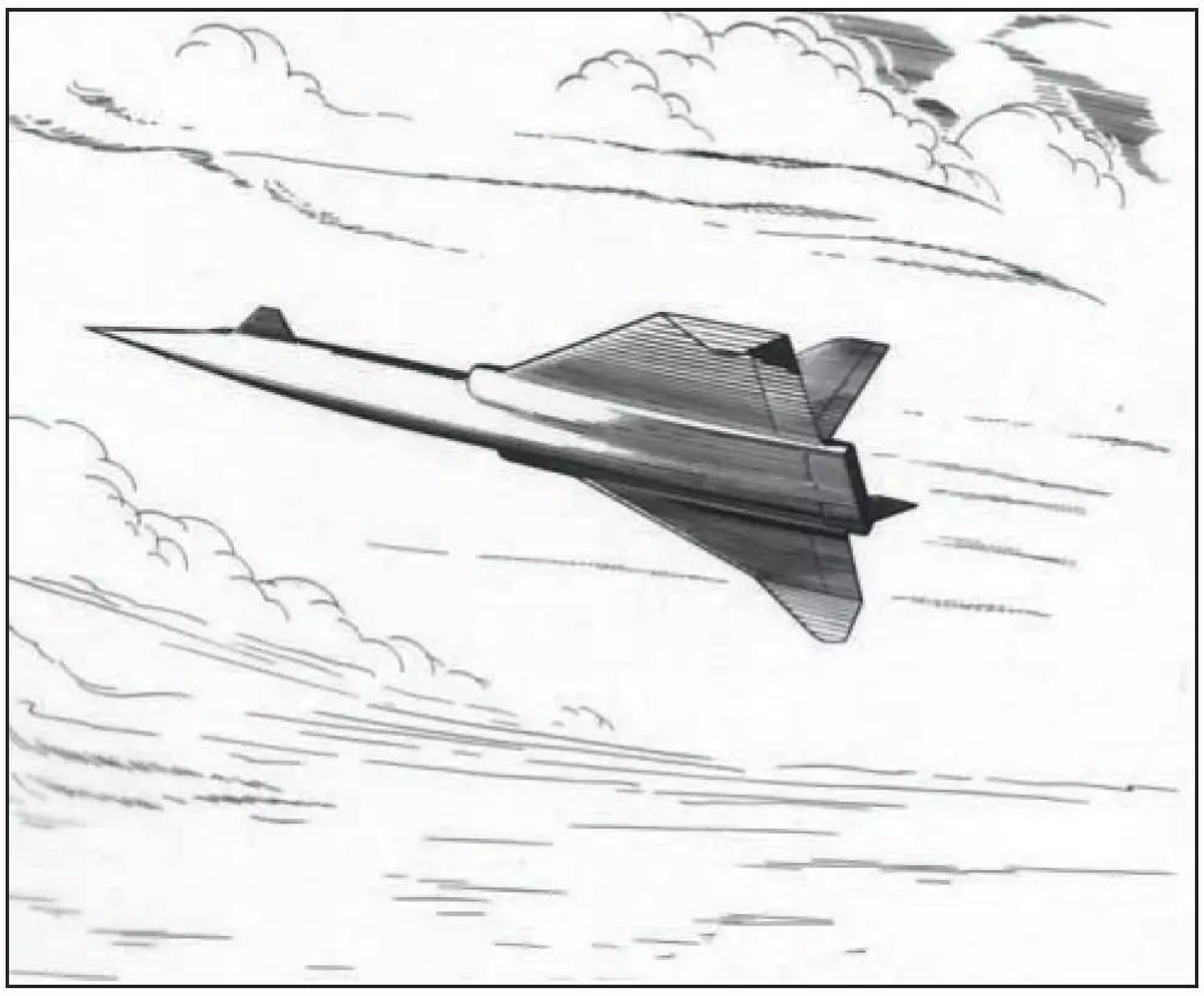




Two photographs of a beautiful desk model which provide a good impression of the Dassault SST. *Dassault Aviation, Direction des Relations Extérieures et de la Communication*



Artist's impression of the Dassault Super Caravelle. Note the aircraft is branded 'Sud-Dassault' when the design itself was pure Dassault. *Dassault Aviation, Direction des Relations Extérieures et de la Communication*

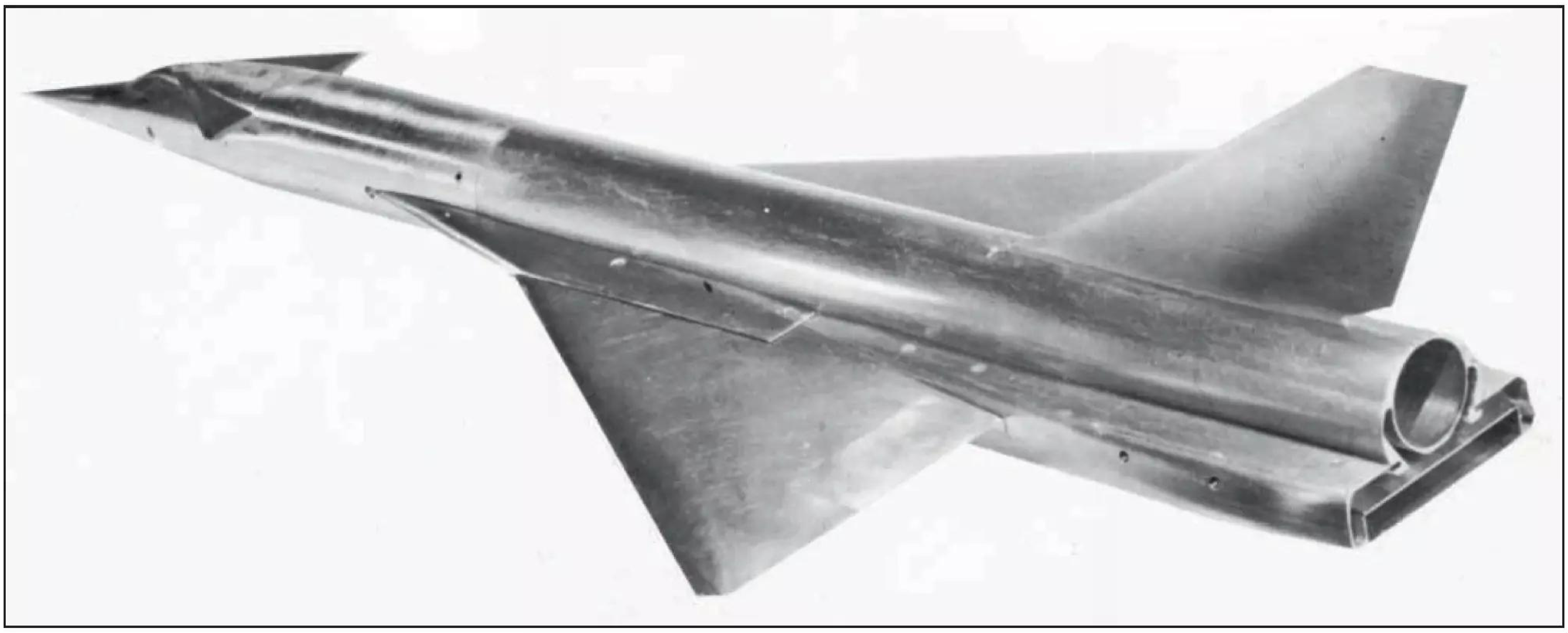


This artist's impression is the only known illustration of the Dassault Super Caravelle with the wingtips angled down for supersonic flight. *Dassault Aviation, Direction des Relations Extérieures et de la Communication*

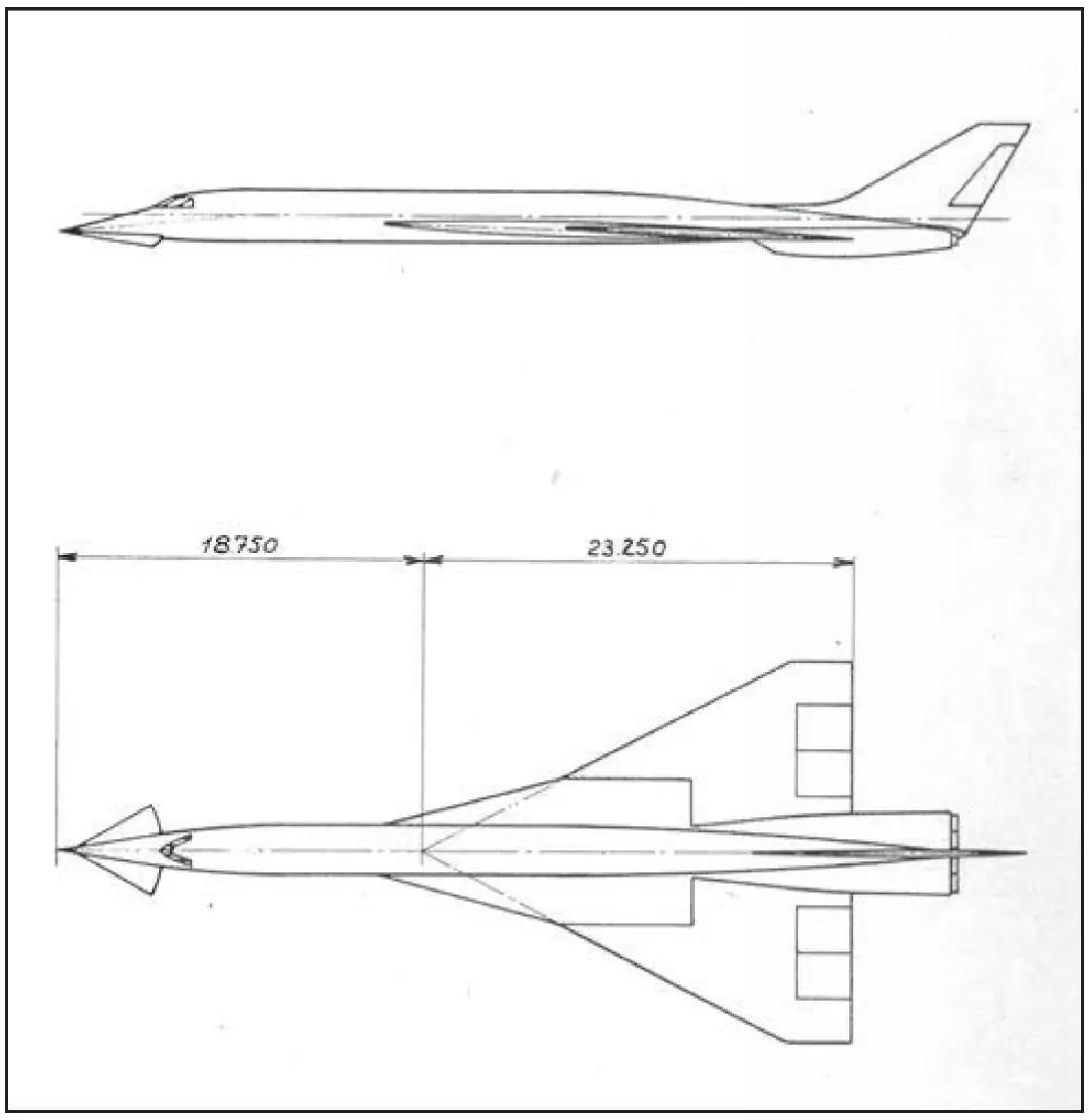
DASSAULT VARIABLE GEOMETRY SST

Dassault was distrustful of variable geometry (VG) wings, pointing out that there had been many VG proposals worldwide but few real aircraft. However, with the objective of improving both range and operating cost, the firm offered a variant of its SST that featured a "somewhat discreet" VG which, so it claimed, "had the advantage of being possible and would provide a noticeable performance gain." Rather than having the wing moving backwards and forwards, the outer wing sections folding down during supersonic flight by means of a hydraulically-operated jack.

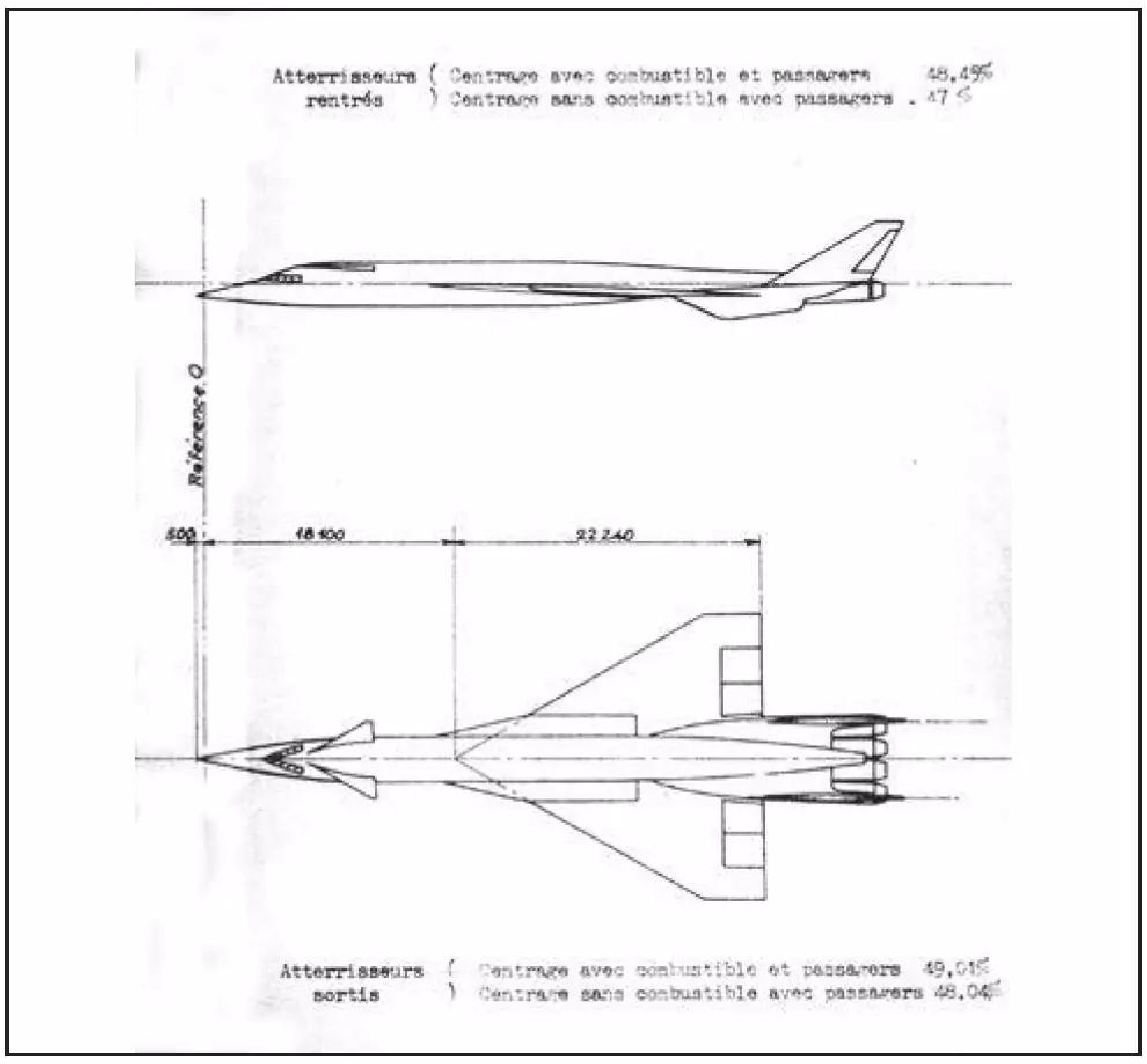
The base project was not altered in any major way, the most visible difference between the two variants being



Wind tunnel model of the Mach 3 Nord Aviation SST proposal. The model has special equipment (air nozzles) to simulate the operation of the turbo-ramjet. *Nord Aviation*


18750
23.250

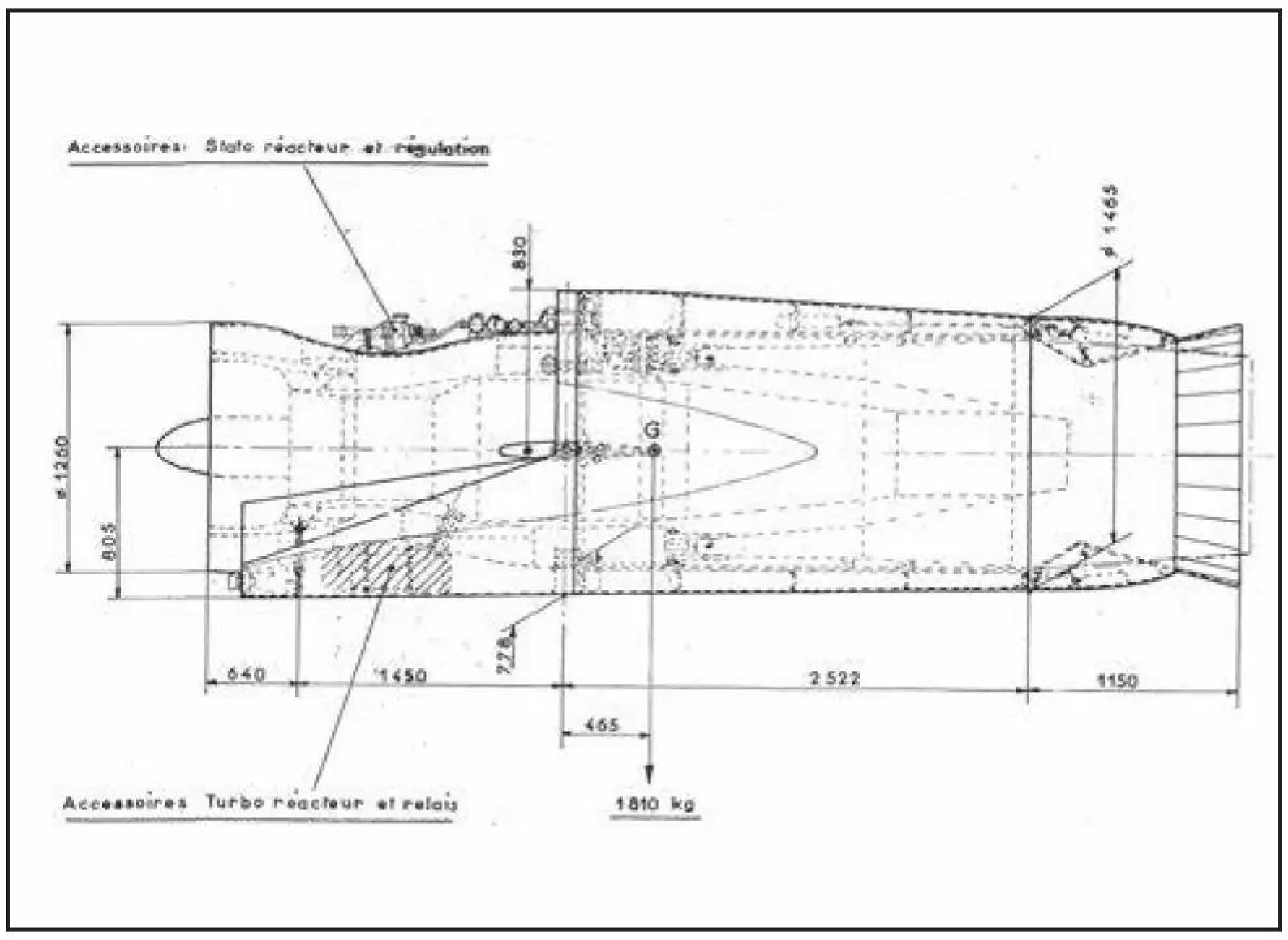
Two views drawing of the Nord Aviation Mach 2 SST. Nord Aviation never called its proposal a 'Super Caravelle', leaving this to Sud and Dassault. *Nord Aviation*


Atterrisseurs rentrés (Centrage avec combustible et passagers 48,49%
) Centrage sans combustible avec passagers . 47 %
Référence O
500
18 100
22 240
Atterrisseurs sortis (Centrage avec combustible et passagers 49,01%
) Centrage sans combustible avec passagers 48,04%

This drawing illustrates and emphasises the differences between the Nord Mach 2 and Mach 3 proposals which, although superficially similar, differ in many points – position of the canard surface, one vertical fin for the Mach 2 aircraft, two fins for the Mach 3 aircraft etc. *Nord Aviation*

the removal of the lower fuselage fin which was no longer required due to the improved supersonic stability obtained from the folding wings. The size of the wings was slightly enlarged and the fittings/equipment needed to move the outer wings added 900kg (1,984lb) to the airframe weight. For centre-of-gravity (cg) considerations, the wing was moved 50cm (19.69in) rearwards and the overall gain from these alterations was a range increase of 200km (124 miles).

The new configuration was wind tunnel tested at the Institut Aéronautique de Saint-Cyr in January 1961. Initially a 1/25th model of the Mirage IVB (a larger unbuilt variant of the Mirage IV bomber) was modified with new wingtips. Another model in 1/31st scale, originally representing the 240sqm base design, was also modified to replicate the wing shape tested on the Mirage IVB model, and this was tested in the same subsonic wind tunnel from March-April 1961. The use of canard surfaces, or not, was also explored as were two different fold angles, 60° and 90°. The results favoured the 90° fold which brought a slight gain in drag and a forward movement of the cg of 3.5%. Removing the canards amplified the increase in drag but reduced the cg displacement.


Accessoires: Stato réacteur et régulation
830
ø 1465
ø 1250
805
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728
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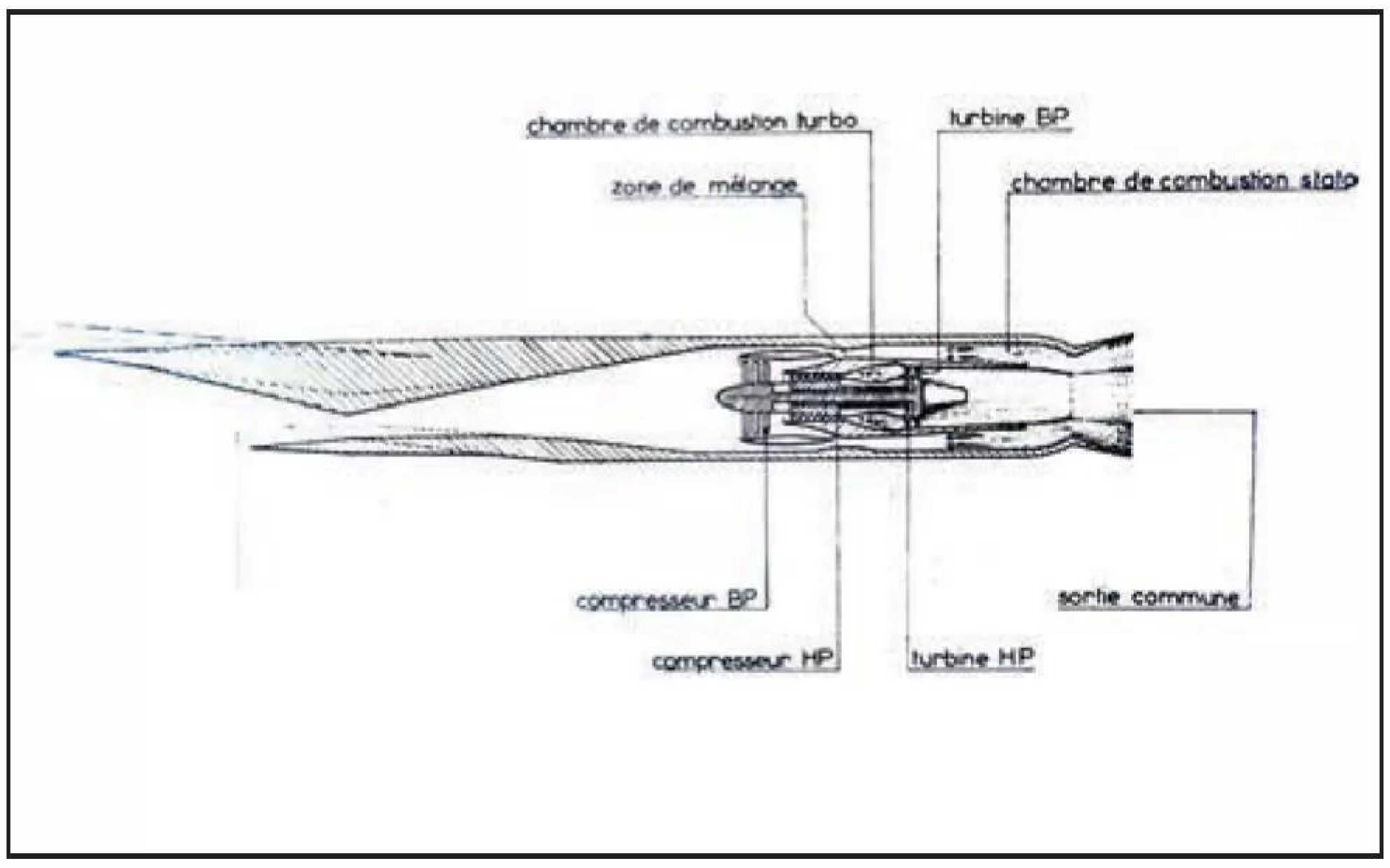
Accessoires Turbo réacteur et relais
1810 kg

Dimensional drawing of the X-51 turbo-ramjet. *Nord Aviation*



Sectioned view of the Nord Aviation turbo-ramjet engine. Note the movable lip of the intake leading to the mouth of the duct feeding both the ramjet and the turbojet element of the engine. *Nord Aviation*

NORD AVION DE TRANSPORT SUPERSONIQUE

Nord Aviation, with Claude Flamand as its project designer, produced two proposals which had a lot in common, one adapted for Mach 2 and the other for Mach 3. For the latter project Nord had designed a turbo-ramjet called the X-51, which was built around the American Pratt & Whitney JTF10 jet with a bi-dimensional air intake and convergent-divergent exhaust nozzle.

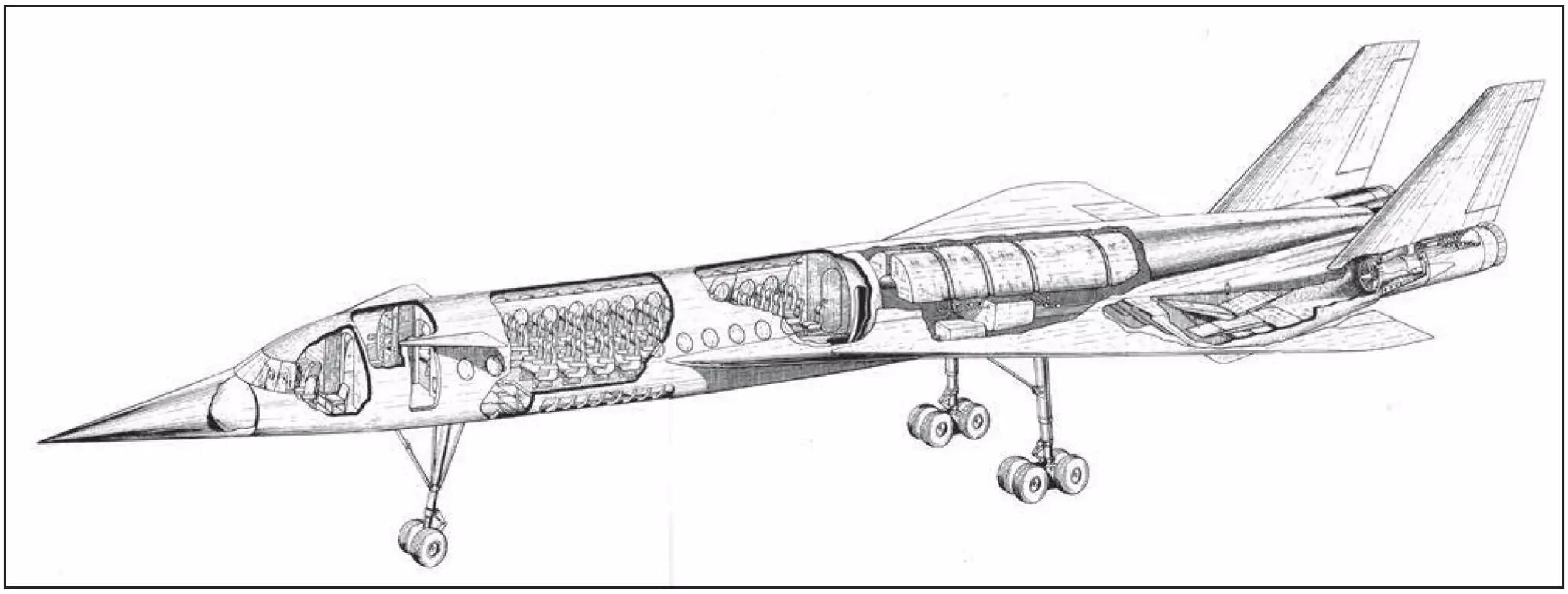
For the Mach 2 medium range proposal, the airframe was composed of five main sections – wings, fuselage, fin, front stabilizers and engine fairings – and the latter parts were incorporated into the fuselage to form its rear section. There was a tricycle-type landing gear with the main gear attached to side bulges on the fuselage which Nord called 'stumps'.

The pressurised section of the fuselage was 22.5m (73ft 10in) long and had a diameter of 3.20m (10ft 6in). The crew comprised two pilots, a flight engineer/radio, one steward and a hostess for 70 passengers. A 15cu m (530cu ft) cargo bay was also enclosed within the pressurised section. Advanced avionics would compensate for the lack of a navigator.

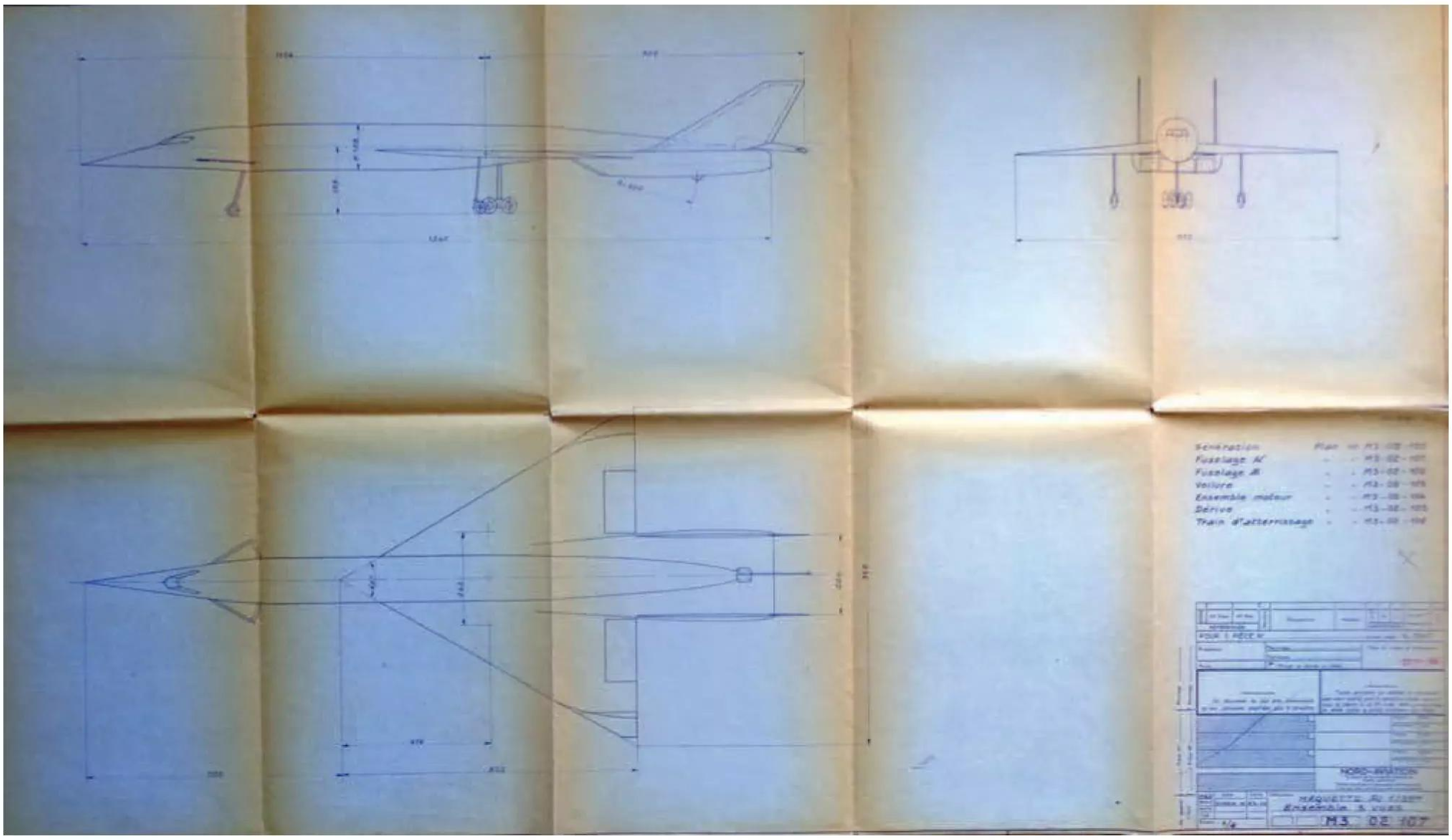
For propulsion Nord used four RB.167/1 engines with reverse thrust installed underneath the rear fuselage inside individual covers. Each engine was independent and interchangeable with the other three and they were fed by four ducts under the wing, admitting air through four rectangular variable section intakes.

The brochure also described a revised variant with a slimmer 2.80m/9ft 2in diameter fuselage and seating for 72. This would have four 20,000lb (88.9kN) thrust Rolls-Royce RB.169s and would have been slightly shorter with a span of 20.14m (66ft 1in) but with a larger wing area of 275sqm (2,957sqft). Nord claimed to have used data from its 1500 Griffon high speed research aircraft as the basis for its SST calculations and the cost of each individual aircraft was given as $4.5m.

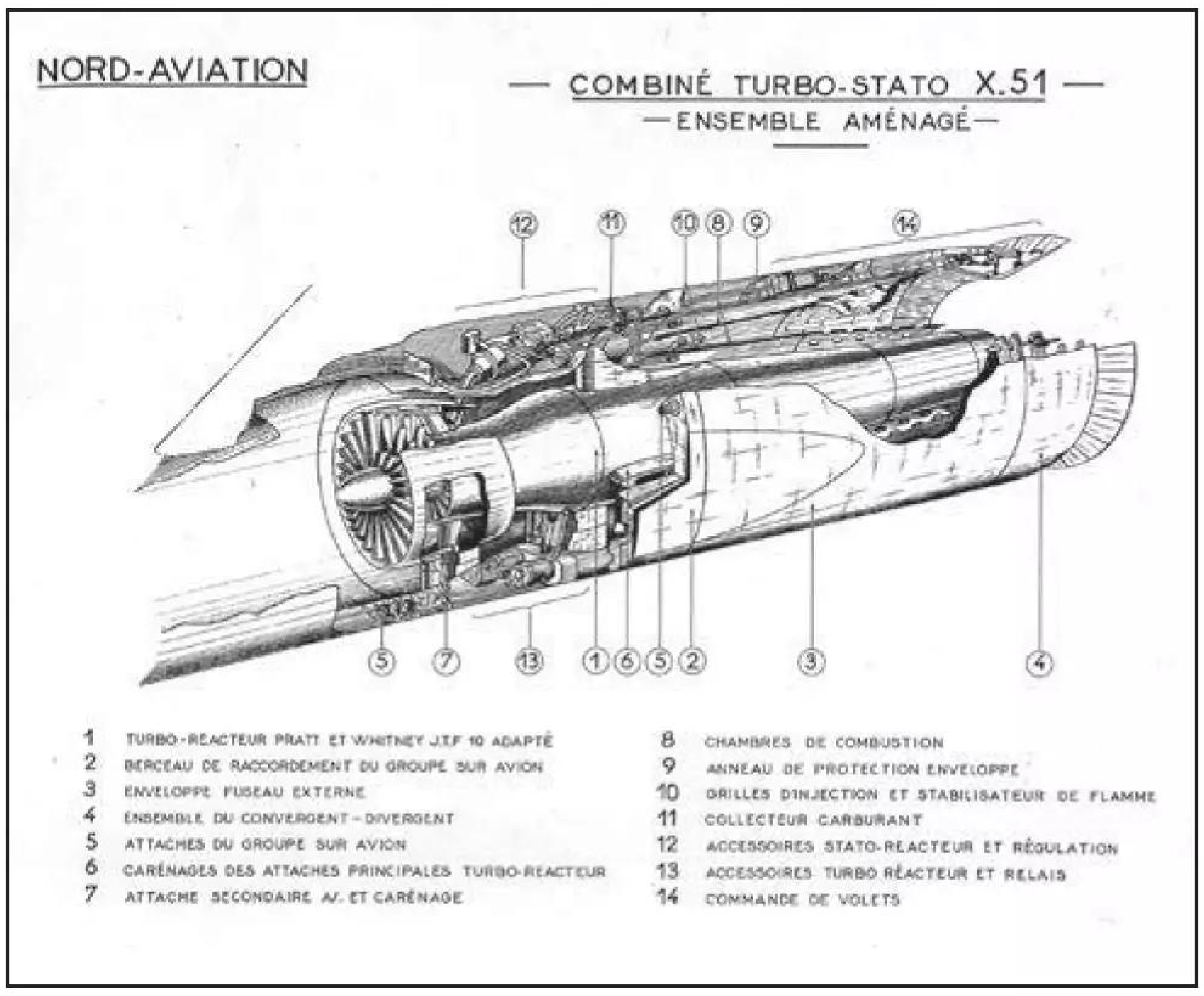
For its 70-passenger Mach 3 proposal, Nord used thin stainless-steel panels stiffened through corrugating for the skin and Vasco 1000 steel for the main structural frames. The difficulty of working with these materials was noted.



Phantom view of the Nord Mach 3 proposal displaying the interior of the passenger section, the large fuel tanks and the complex air ducts with many moving flaps. The turbo-ramjets are rather small when considering the overall size of the aircraft. *Nord Aviation*


Fuselage AV
Fuselage AR
Voilure
Ensemble moteur
Dérive
Train d'atterrissage
NORD-AVIATION
Ensemble 3 vues
M3 02 107

The Nord Aviation Mach 3 proposal. Nord was certain to have an advantage over its competitors with its turbo-ramjet and pushed for the Mach 3 solution which was optimal for ramjet operation. *Nord Aviation via JC Carbonel*


NORD-AVIATION
COMBINÉ TURBO-STATO X.51
ENSEMBLE AMÉNAGÉ
12
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1
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3
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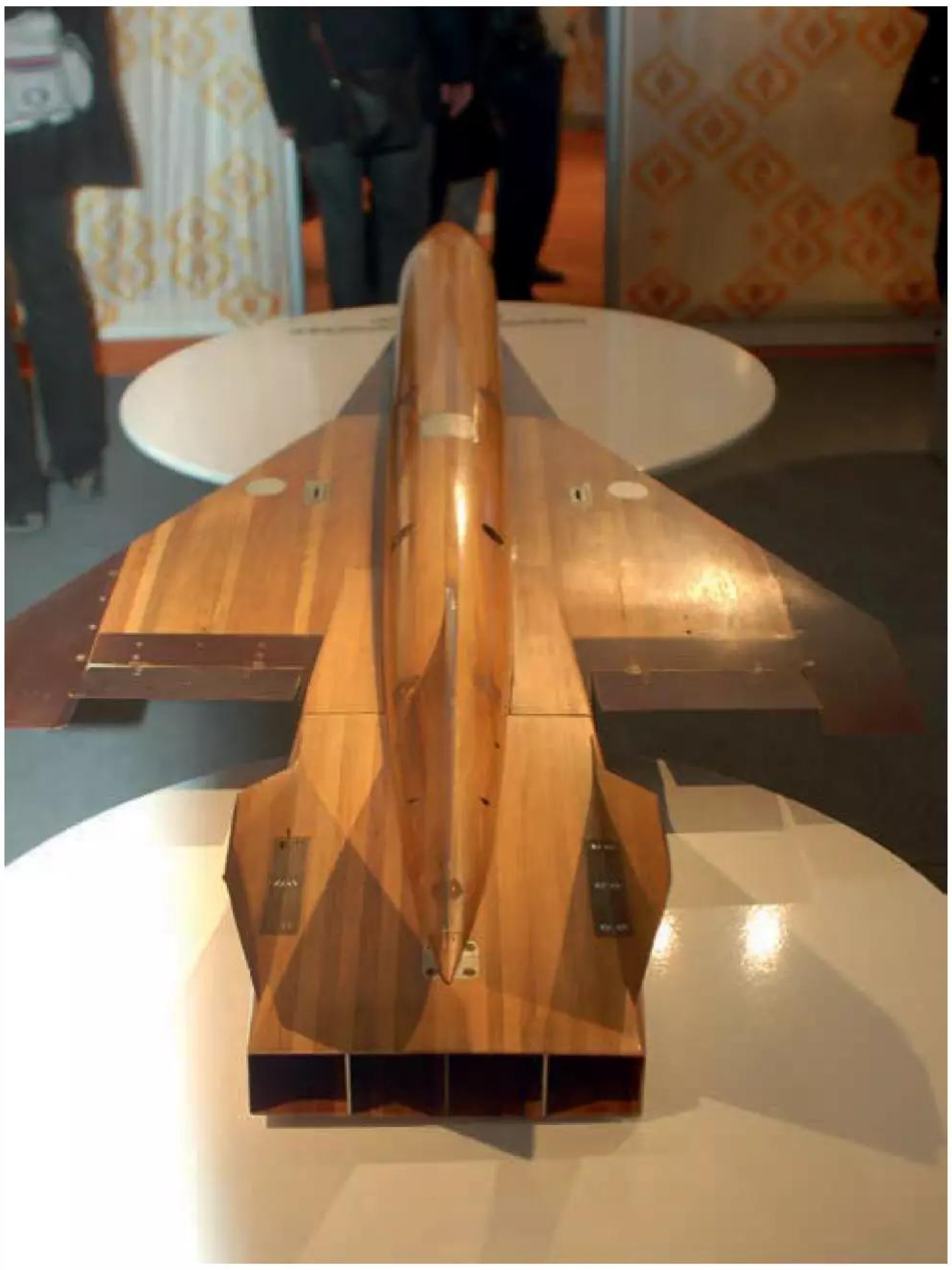
1 TURBO-RÉACTEUR PRATT ET WHITNEY J.T.F 10 ADAPTÉ
2 BERCEAU DE RACCORDEMENT DU GROUPE SUR AVION
3 ENVELOPPE FUSEAU EXTERNE
4 ENSEMBLE DU CONVERGENT - DIVERGENT
5 ATTACHES DU GROUPE SUR AVION
6 CARÉNAGES DES ATTACHES PRINCIPALES TURBO-RÉACTEUR
7 ATTACHE SECONDAIRE AV. ET CARÉNAGE
8 CHAMBRES DE COMBUSTION
9 ANNEAU DE PROTECTION ENVELOPPE
10 GRILLES D'INJECTION ET STABILISATEUR DE FLAMME
11 COLLECTEUR CARBURANT
12 ACCESSOIRES STATO-RÉACTEUR ET RÉGULATION
13 ACCESSOIRES TURBO RÉACTEUR ET RELAIS
14 COMMANDE DE VOLETS

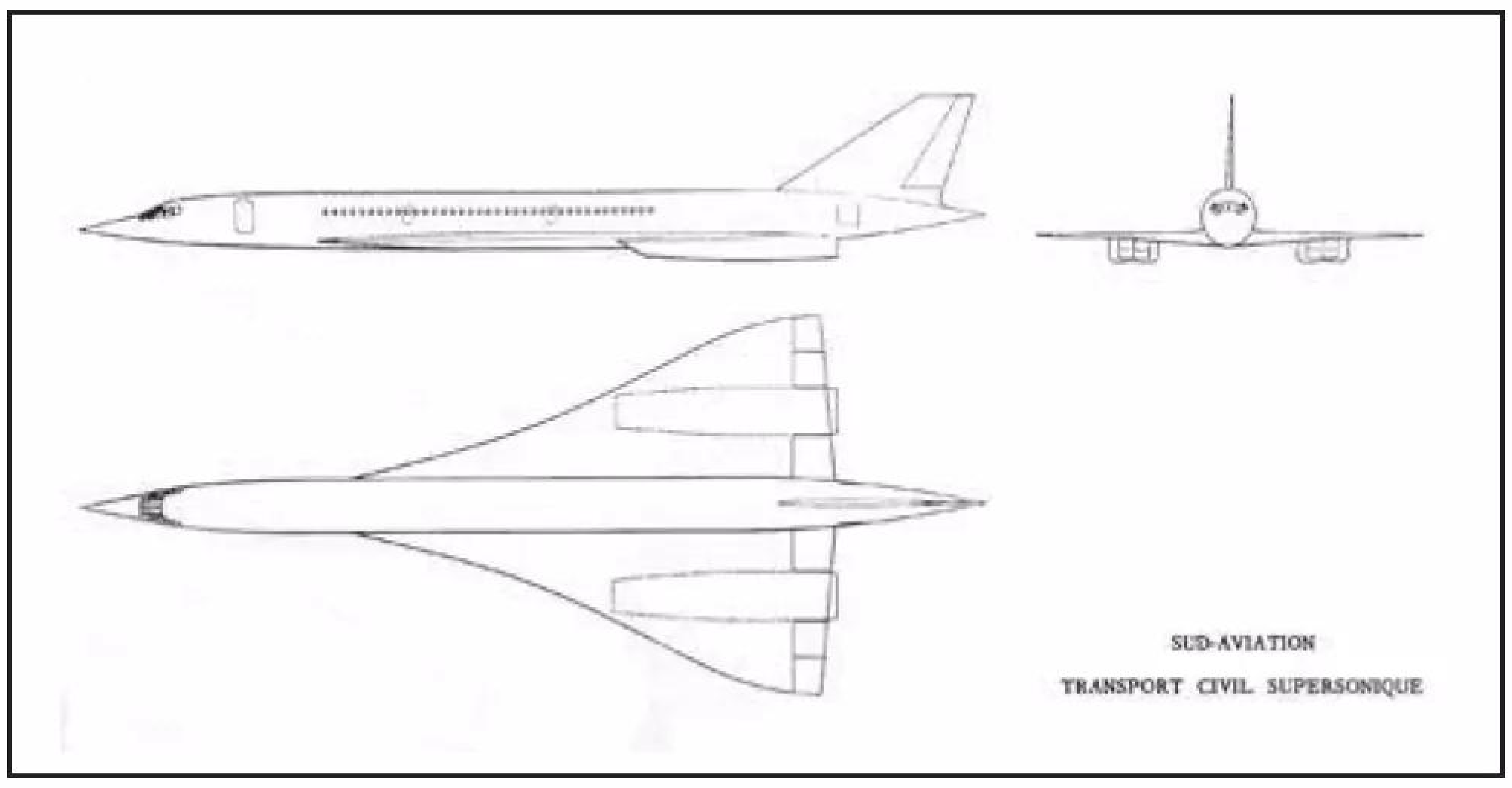
Ghost view of the X-51 turbo-ramjet engine designed by Nord on the basis of its Griffon research aircraft experience. *Nord Aviation*

The adaptation to ramjet operation also involved a reworking of the turbojet's outer shell and a new convergent-divergent nozzle would have to be designed. Again, for the X-51 Nord referred to its Griffon experience and different positions for the engines on the SST airframe had been considered, in particular the solution finally adopted for the Concorde itself with the engines grouped in pairs under the wings. In the end, however, drag studies for this Nord project led the design team to group all four engines together at the rear of the fuselage.



Model of the Nord Mach 3 SST proposal photographed in the Toulouse Air Museum in 2009. *Copyright Ph. Van lierde/AIRITAGE/2009*

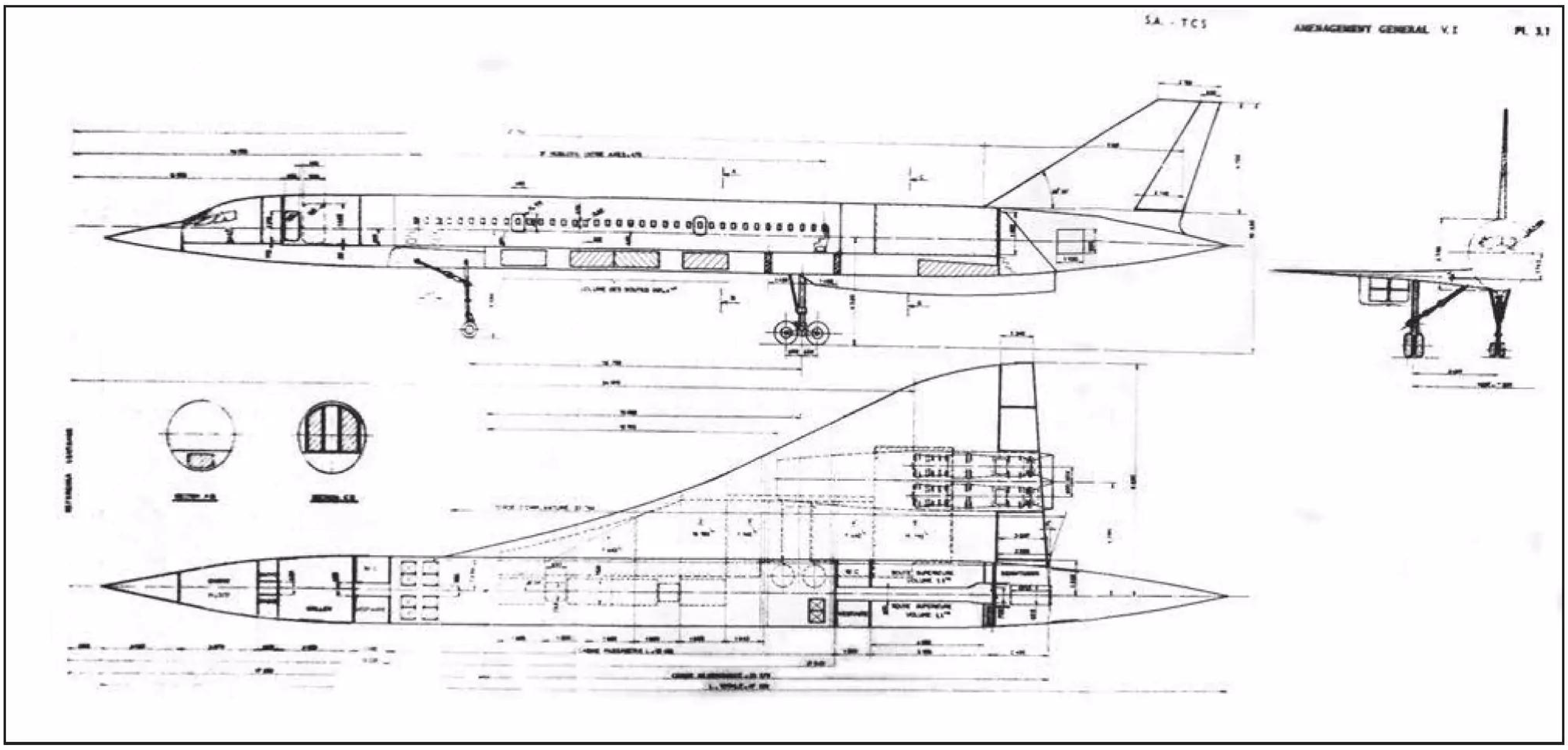
The Nord 1500 Griffon II prototype photographed during the Paris Air Show on 4 June 1961. The Griffon was instrumental in giving Nord experience in high speeds and turbo-ramjet engines. Even more important for our story this aircraft was also flown by Concorde test pilot André Turcat! *JC Carbonel*



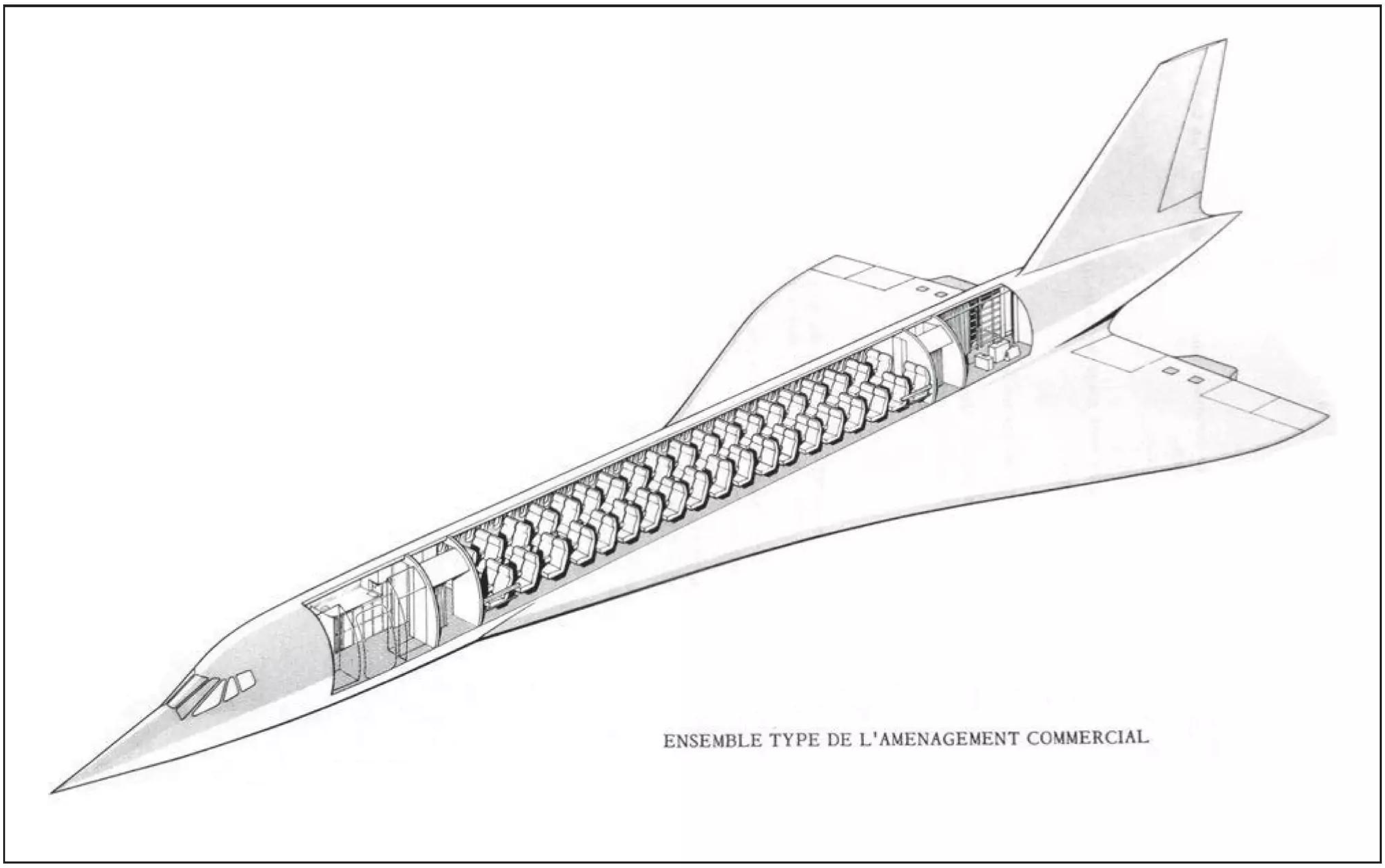
General three-view of the Super Caravelle as of April 1961. *Sud Aviation via JC Carbonel*

The delta wing had a sweep angle of 60° and a thickness of 2.5% and, because of the difficulties expected in terms of stability at Mach 3, there were two large fins attached to the upper and outer engine section. The fuselage had a diameter of 3.2m (10ft 6in), the front section was pressurised and contained the cockpit and the cabin while the rear, near the cg, housed the fuel tanks.

Placing the fuel in the fuselage was expected to facilitate screening from the effects of the build up of heat, which Nord thought would be hard to with wing tanks. The flight crew comprised a captain, co-pilot, flight engineer and if required a controller. All of the flight controls would be fly-



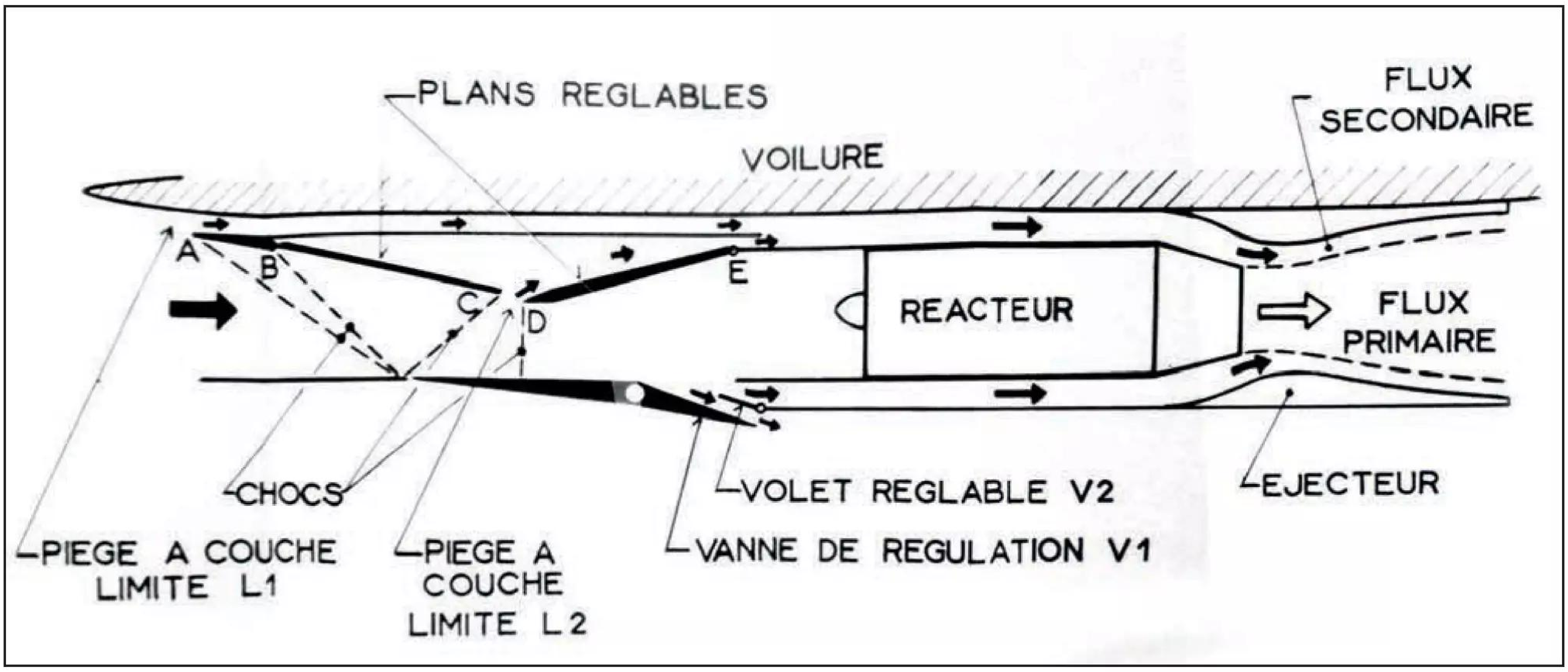
On the original copy of this drawing can be read from the nose to rear: cockpit, galley, vestiaires (cloak-room), cabine passagers (passengers cabin) and soute supérieure (above deck luggage bay). *Sud Aviation via JC Carbonel*


ENSEMBLE TYPE DE L'AMENAGEMENT COMMERCIAL

Again from the April 1961 brochure, a ghost view revealing the intended furnishing of the Transport Civil Supersonique. *Sud Aviation via JC Carbonel*

by-wire with a television screen relaying information from the ground.

Nord tried to evaluate the cost of operating its aircraft but was quite conscious that "it appears audacious to give cost estimates, even approximately. The aircraft is so different from known aircraft which are presently in operation that data gained from them is of dubious utility. Besides we are working from computed performance data based on theoretical aerodynamics {and] it is obvious that training of the crew members will require considerable investment, [which is] still not well known."


PLANS REGLABLES
VOILURE
FLUX SECONDAIRE
A
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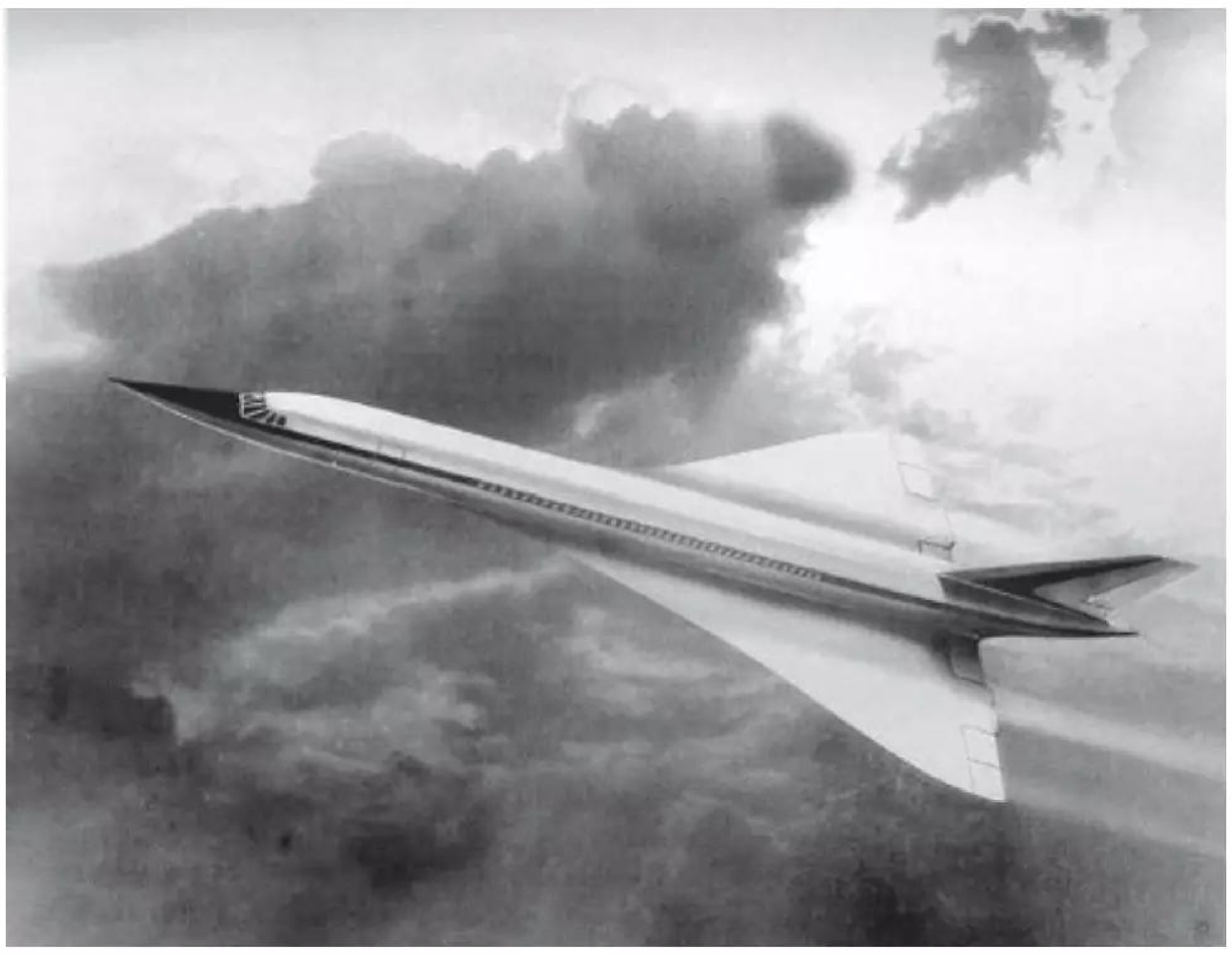
E
REACTEUR
FLUX PRIMAIRE
CHOCS
VOLET REGLABLE V2
EJECTEUR
PIEGE A COUCHE LIMITE L1
PIEGE A COUCHE LIMITE L2
VANNE DE REGULATION V1

Like Nord Aviation, Sud Aviation recognised the need for complex air ducts to feed the turbojets which featured numerous moving lips and a complex exhaust arrangement to adapt the airflow for subsonic and supersonic conditions. This illustration comes from the April 1961 Super Caravelle brochure. *Sud Aviation via JC Carbonel*



A rare artist's impression of the Super Caravelle in its 1961 state.
Sud Aviation via JC Carbonel

SUD SUPER CARAVELLE I/II

Sud's proposal of 30 April 1961 was labelled just 'Super Caravelle' and offered in two versions – the base variant plus a second with a slightly stretched fuselage. Strangely the brochure gave only one fuselage length, and even the drawings which depicted both variants presented a scale rule but no specified written dimensions.

The baseline engine was the RB.169/2 without 'plug nozzle'. It was noted that "the Bristol Siddeley Company is studying, for use in supersonic transports, a development of the Olympus turbojet which is expected to be installed on the British TSR.2 strike aircraft. The 'civil' version of this turbojet is called the BS.593 and it has been verified, at all stages of the project, that it will be possible to install the Bristol turbojet [on the Super Caravelle], which characteristics are somewhat similar to the Rolls-Royce turbojets."

The 'Version I' seating arrangements included 57-63 all first-class passengers, or 76-84 as tourist class, or 84-92 with high density seating, and luggage bays in the lower fuselage and at floor level occupied 4cu m (141cu ft) and 11cu m (388cu ft) of space respectively. These arrangements were assessed in a 5m (16ft 5in) long full-size mock-up.

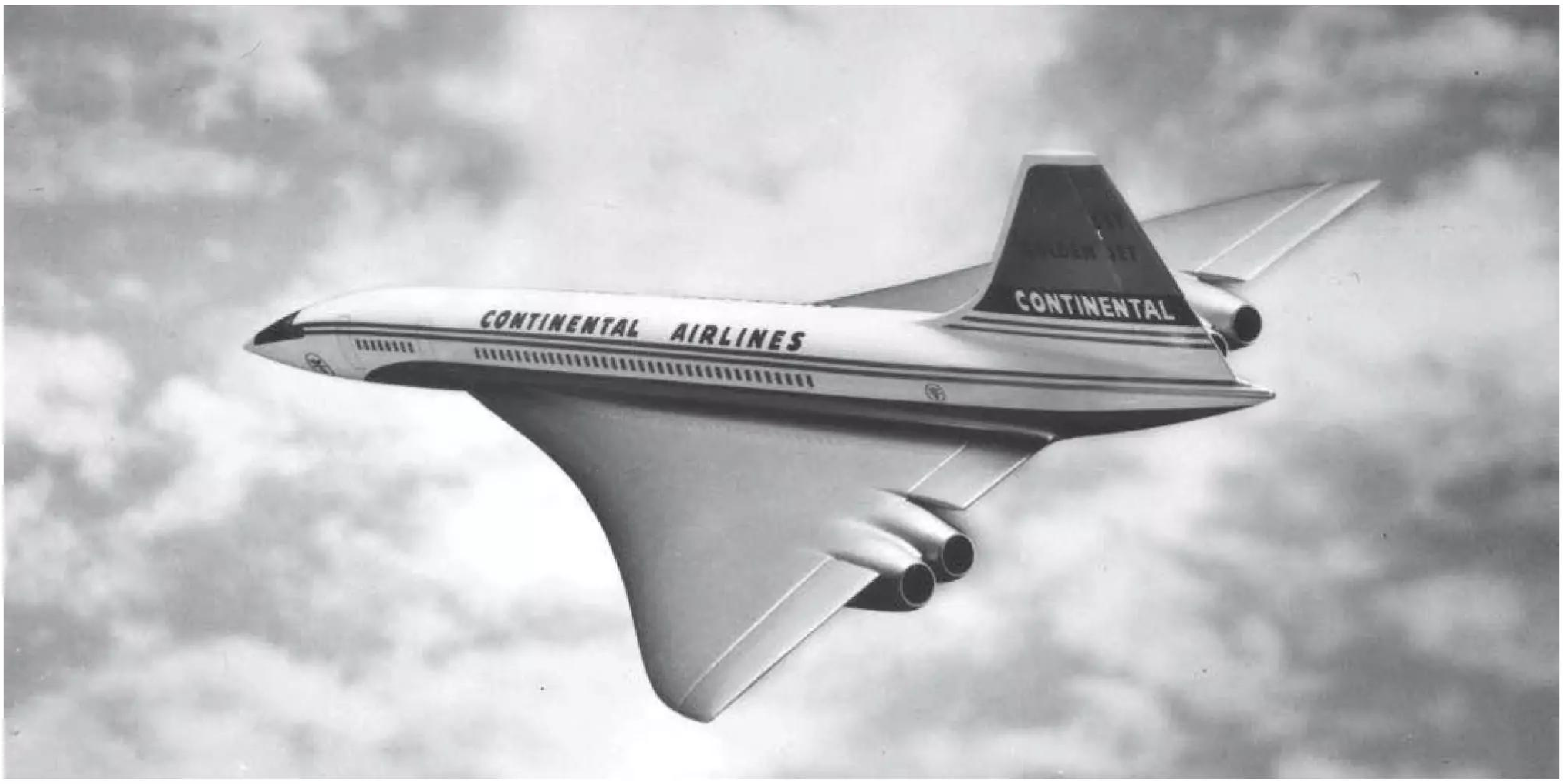
Dollar price quoted for the complete airliner was $5.6m. Wind tunnel testing involved a large wooden model for low speed tests while metal models of 1/70th and 1/180th scale were used for high speed research.

Mention has been made already that the Super Caravelle was first displayed publicly as a project at the May 1961 Paris Show. Neither Dassault nor Nord displayed their projects at le Bourget, but the show clearly revealed that the French had become very enthusiastic towards an ambitious SST programme.

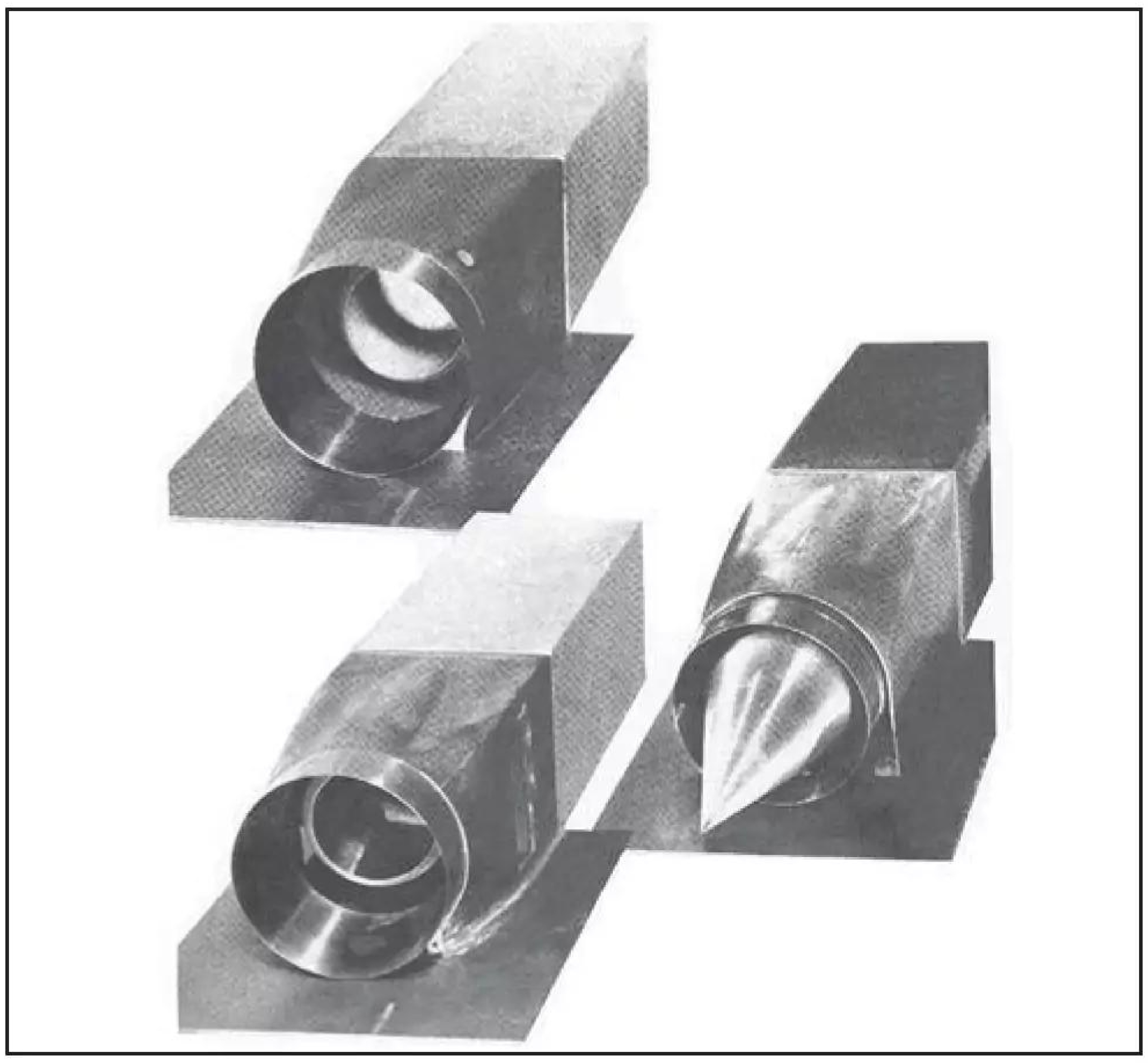
SUD GETS THE GO-AHEAD

On 21 November a Conseil Interministeriel (a French government function in which various Ministries were represented) approved the launch of the 'supersonic programme' based on the Sud Super Caravelle fitted with Bristol Siddeley Olympus turbojets.

During the autumn of 1961 the British supplied the French with details of BAC Filton's latest SST proposal. An early assessment made by Sud Aviation of the BAC Type 223 dated 28 September 1961 noted that at face value the technical data was "more favourable than for the Super



An early Concorde (or late Super Caravelle) model in the markings of Continental Airlines. The four separate jet nozzle arrangement is unusual.
Philippe Ricco collection



SST nozzle models which had been studied by SNECMA. Note the example with the 'plug' and compare the others with the picture of the model in "Continental airlines" markings. *SNECMA – Espace Patrimoine Safran*

Caravelle" but added that in terms of commercial use "actually, this plane can only carry 90 passengers".

A more detailed analysis of 30 November presented a rather harsh technical review of the Type 223, criticising the weight balancing, "bad partitioning" between the passengers and freight, load factors at all speeds, fuselage diameter incompatibility with pressurisation, too-small vertical stabiliser and even what was to become one of the key design features of Concorde: "It is difficult to justify the variable geometry [droop] nose in view of the weight it generates from the [additional] hydraulics [needed to operate it]".

That same day Sud Aviation issued a memo by Jean de Lagarde which compared the marketing evaluation of the SST by the French and the British teams. It concluded that "the British estimate a probable market in 1975 of 180 SSTs out of which 90 are medium range and 90 are long range, excluding the US airlines. In the same conditions we arrive at a minimum of 109 SST out of which 91 are medium range and 18 are long range. Including the US airlines we evaluate the market at 143 medium range and 23 long-range aircraft. The ratio long/medium range will therefore be smaller than that announced by the British study, especially if the US airlines are taken into account."

SUD SUPER CARAVELLE IIIA AND IIID

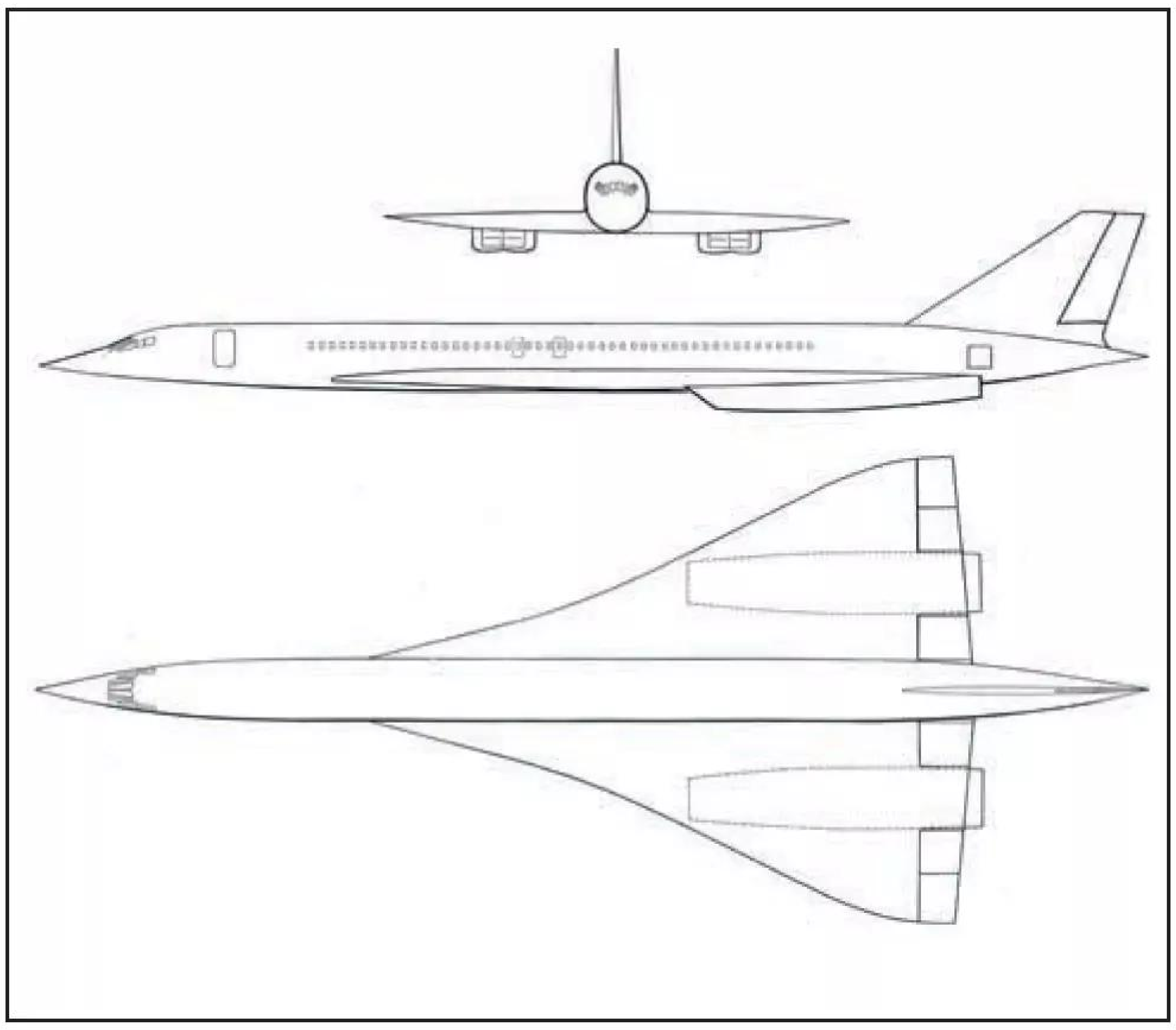
A new Sud brochure dated 18 November 1961 described the Super Caravelle IIIA and IIID, the latter a transatlantic variant of the earlier and undated medium-range IIIA. This brochure for further developed versions of the Super Caravelle had been prompted by the opening of negotiations between British and French officials for a joint SST programme.

The IIIA's fuselage was described as "a long cylinder tapering at both ends" and it contained from the nose to the rear an unpressurised radar nose, the cockpit, a radio bay, galley, passenger cabin with 4 seats abreast, freight bays along a rear access stair and an unpressurised support equipment bay. The lower section of the fuselage was pressurised and included the luggage bays in its centre section with equipment bays on the sides. The cabin could take 100 seats and 25cu m (883cu ft) of freight or 108 seats with the freight reduced to 22cu m (777cu ft).

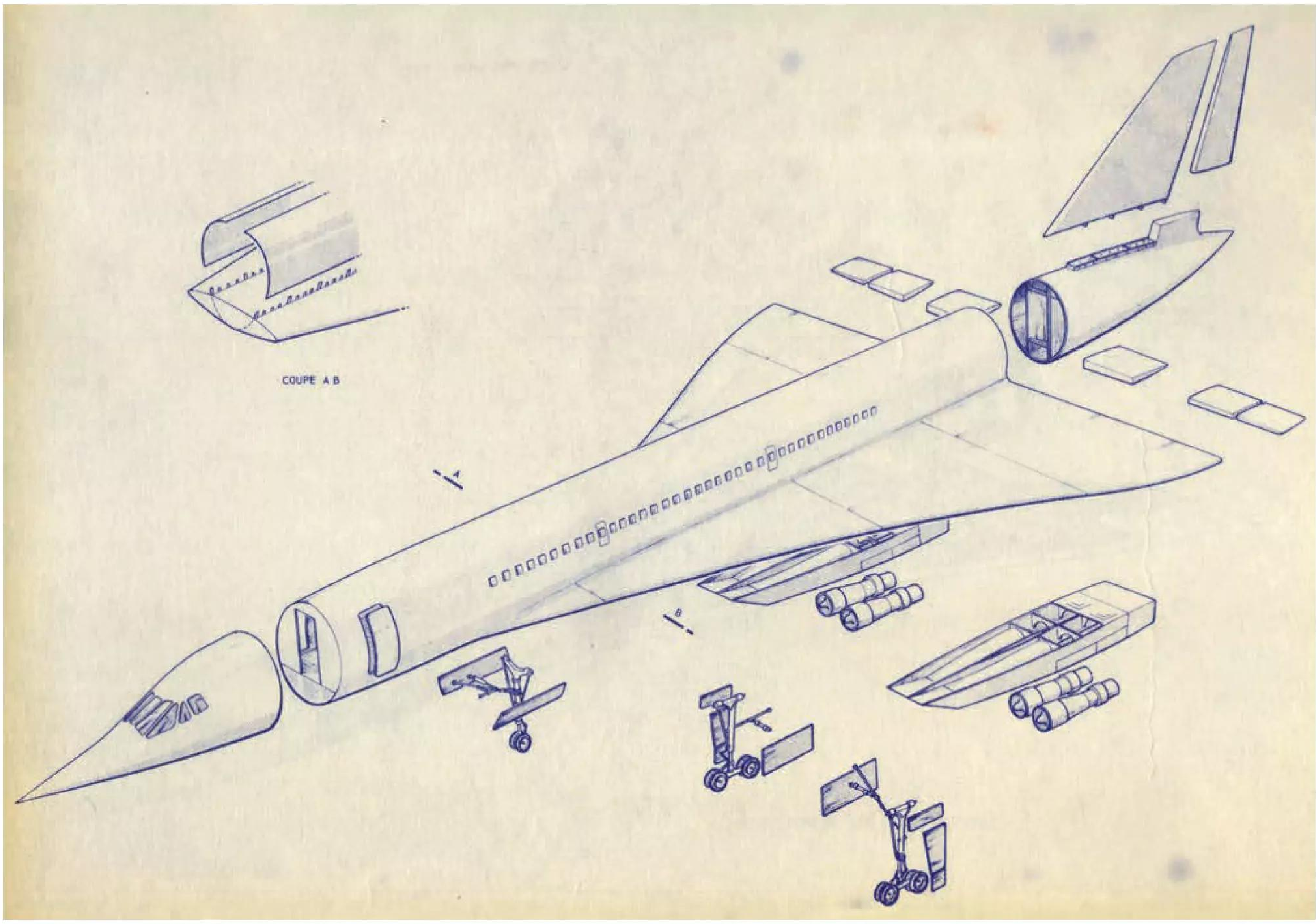
Super Caravelle IIIA's wing was still called a delta, although it had been given what was described as an 'evolutive' sweep. An aerodynamic refinement obtained through the warping and cambering of the wing profiles, associated with a system to control the balance of the aircraft throughout the phases of a flight through fuel tank management, had allowed the overall drag to be kept to a minimum. The wing's relative thickness was 3% at the body line which diminished progressively to 2.15% at the mid-span position and then remained constant.

Two nacelle fairings on the underside of the wing each enclosed a pair of Olympus 593/3 engines, with each having its own air intake with individual control, and boundary layer control was installed at the leading edge of the first 'recompression' ramp.

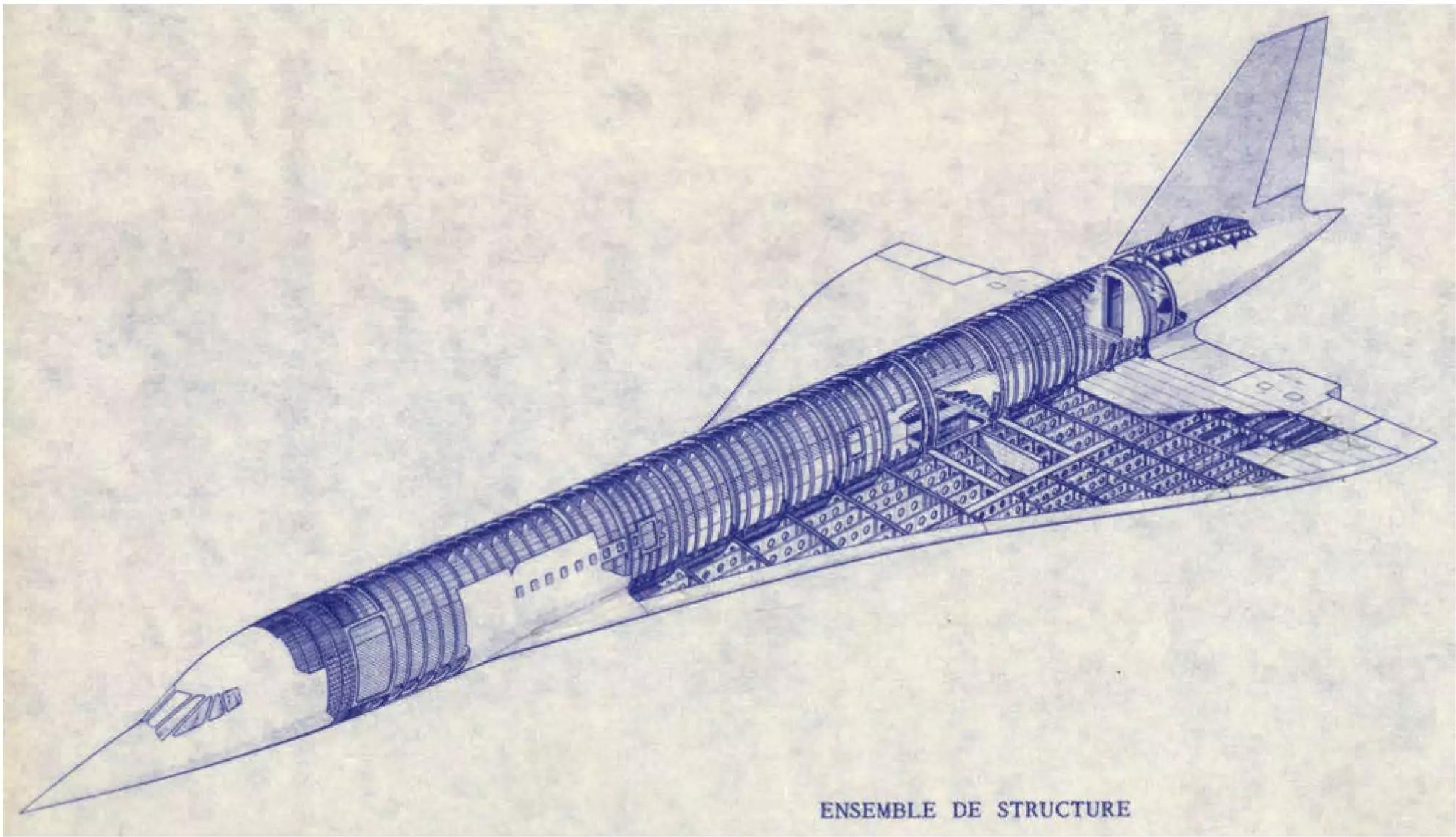
Lateral stability was provided by a single fin at the rear of the fuselage, manoeuvrability in yaw was obtained by a conventional rudder at the trailing edge of the fin which allowed for landings in cross winds of 30 knots (56km/h), and manoeuvrability in pitch and roll was assured by



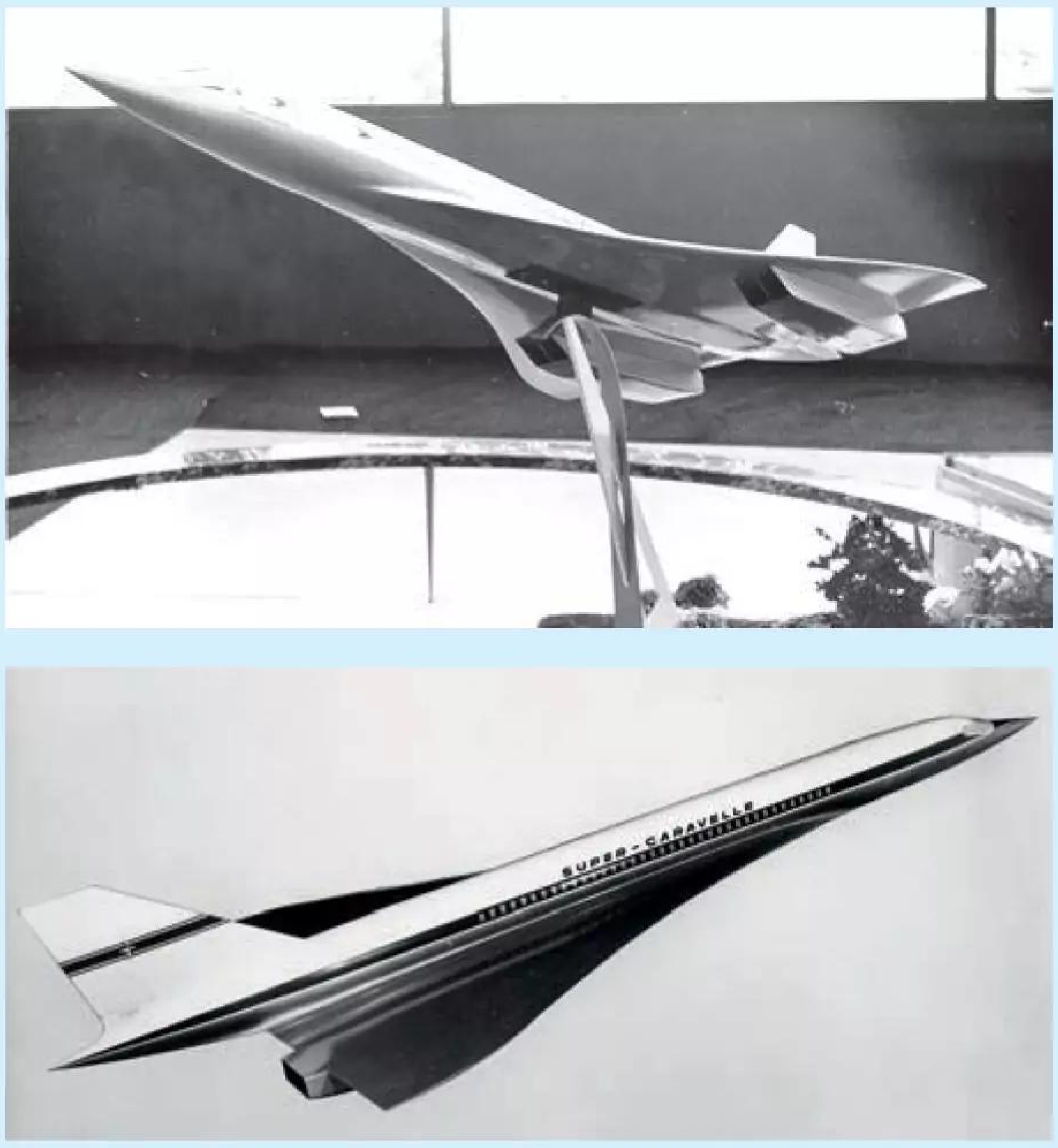
Three view drawing of the November 1961 Super Caravelle III. The aircraft would have used the same airframe for the model A (short range) and model D (extended transatlantic range) versions. *Alan Jenner*



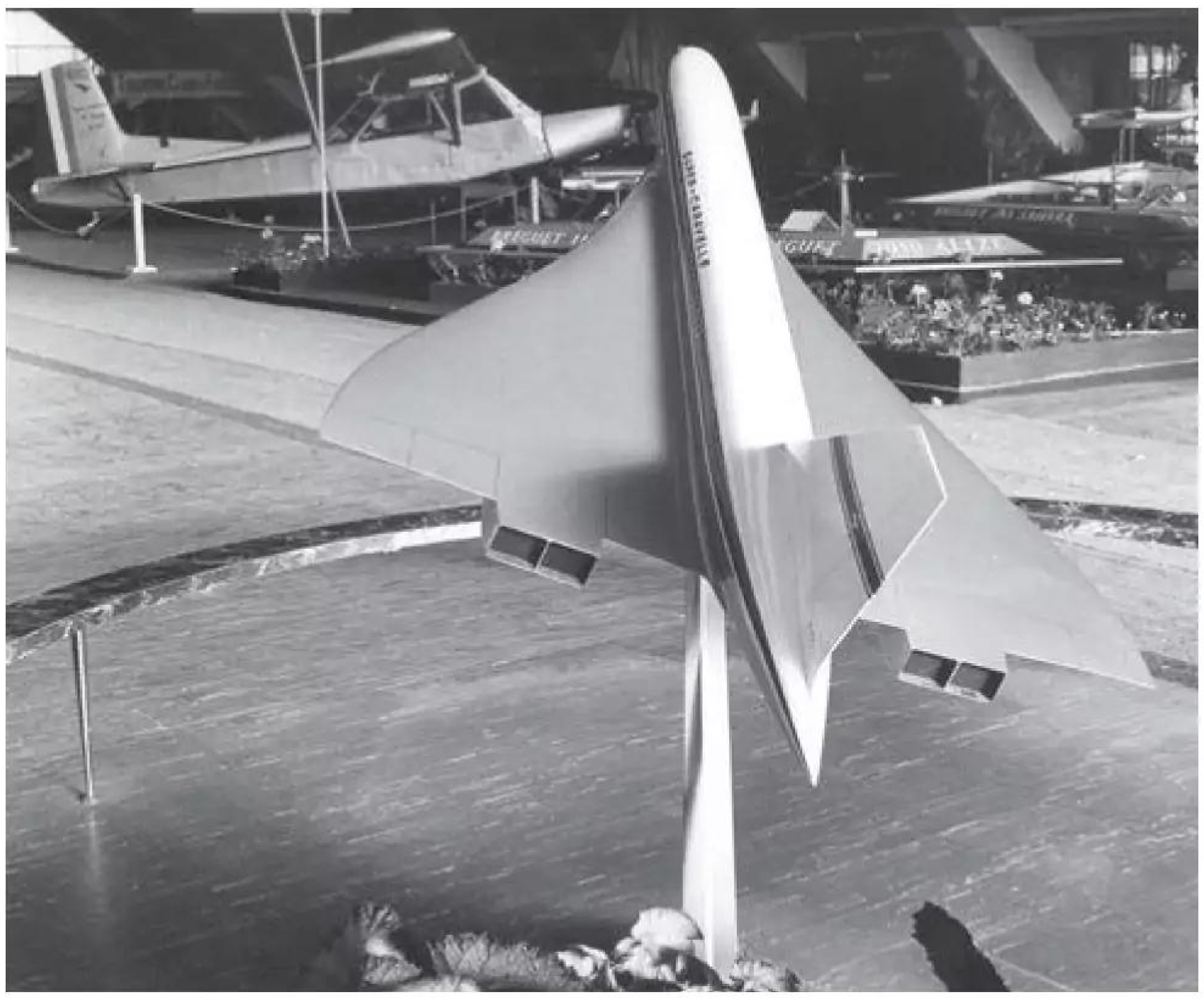
From the April 1961 brochure an 'exploded' drawing showing the different elements that made up a Super Caravelle. *Philippe Ricco*


ENSEMBLE DE STRUCTURE

View of the structure of the April 1961 Super Caravelle. *Philippe Ricco*

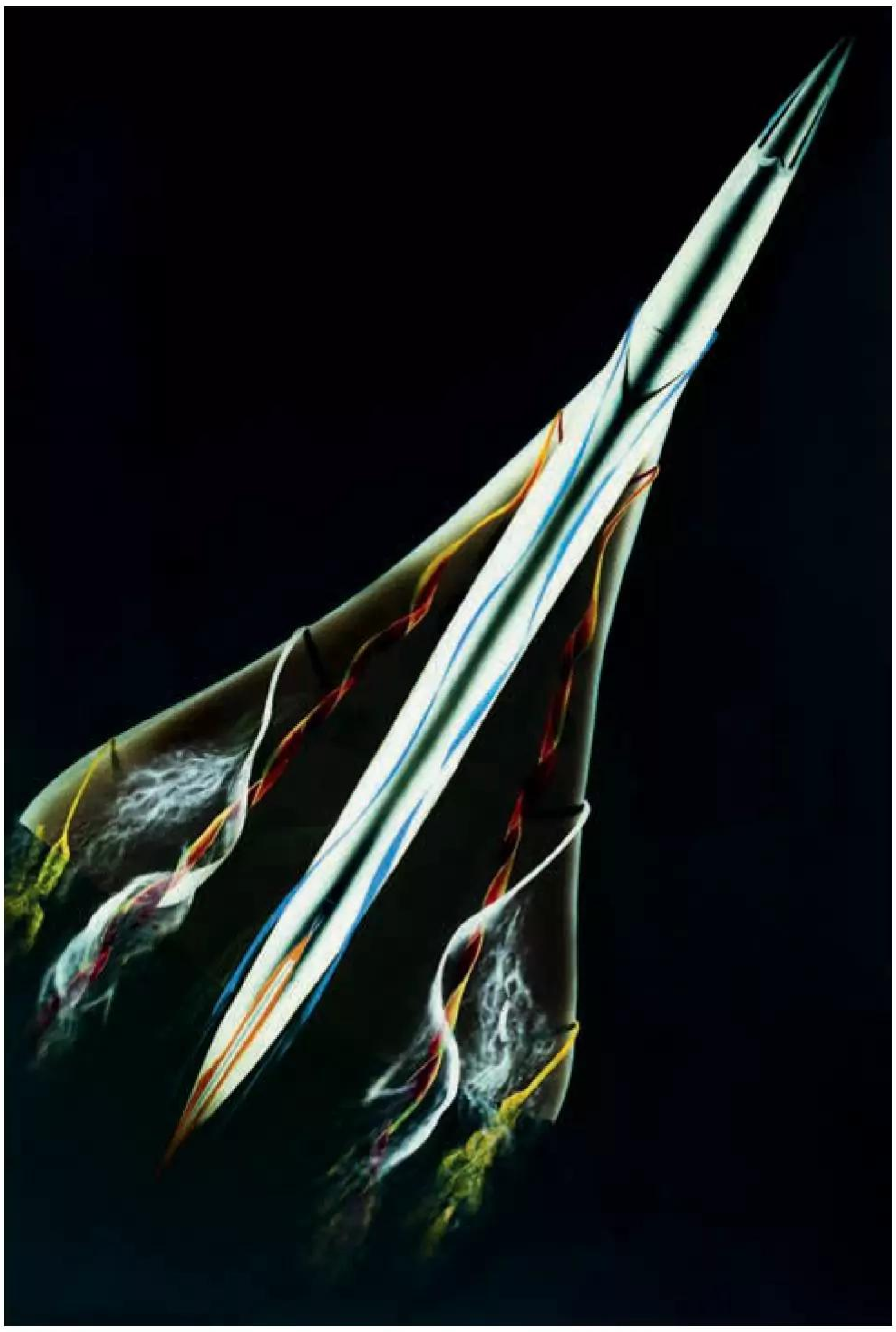


At the 1961 Paris Air Show (held from 26 May to 4 June) Sud Aviation lifted the veil off its Super Caravelle with this large and attractive model. *Copyright AIRBUS/AIRITAGE/D.R.*



The Super Caravelle model was also exhibited at the Toulouse air show on 18 June 1961. *Photo Jean Dieuzaide, Philippe Ricco collection*

trailing edge elevons which occupied the whole of the span except for the portion intersected by the engine jet pipes. The airbrakes consisted of two lateral flaps on the rear fuselage and the nose undercarriage and the bogie units of the main undercarriage retracted beneath the cabin floor. The brochure, showing that the design team was perhaps still 'scarred' by its bad experience from trying canard surfaces two years earlier, noted that the fin "prevented unfavourable aerodynamic interactions", while providing stability over the whole flight envelope.



A classic picture: an ONERA model being tested in a wind tunnel with the airflows indicated by coloured streams. *ONERA via JC Carbonel*

The transatlantic Super Caravelle IIID was derived directly from the IIIA; the aircraft's outward appearance was unchanged but the cabin layout, fuel arrangements and certain structural components had all been modified to achieve a maximum range of 3,250nm (6,022km).

The modifications differentiating the IIID from the IIIA were the reinforcement of the wing spars, fuselage frames and landing gear legs. It was acknowledged that an area ruled fuselage would have led to a better aerodynamic concept but this had been sacrificed in the interest of simplicity of construction and furnishing.

The range increase had required a large increase in the amount of fuel carried. Indeed, it was the increase in take-off weight relative to the carriage of the additional fuel that had made structural reinforcements essential. The increase in supersonic flight time had also led to certain equipment modifications – for example the avionics and navigation systems had to be improved.

The IIIA had 101,200lb (45,904kg) of fuel and for the IIID this rose to 117,360lb (53,234kg). All of the IIIA's fuel was carried in wing tanks but for the IIID it was necessary to put five more tanks into the fuselage, two in front and three in former luggage bays at the rear. The fuel was to be used as a coolant for the air conditioning system and there was a fear that the longer flight time at supersonic speed would lead to over-heating, so a 'baffle anti-convection' system as proposed by BAC was to be used.

Normal take-off speeds were 324km/h (175 knots) for the IIIA and 354km/h (191 knots) for the IIID. Landing speeds were IIIA 258km/h (139 knots) and IIID 267km/h (144 knots). The flight plan for a normal stage length in supersonic flight was: climb at 741km/h (400 knots) to 13,105m (43,000ft); accelerate at 13,105m (43,000ft) to 1,112km/h (600 knots); climb at Mach 2.2 to cruising altitude; decelerate from Mach 2.2 to 556km/h (300 knots); descend at 556km/h (300 knots).

JOINT DECLARATION

On 22 November 1961 the French Conseil des Ministres approved a 1.4 billion franc research programme to support a 'civilian supersonic aircraft', starting from the beginning of 1962.

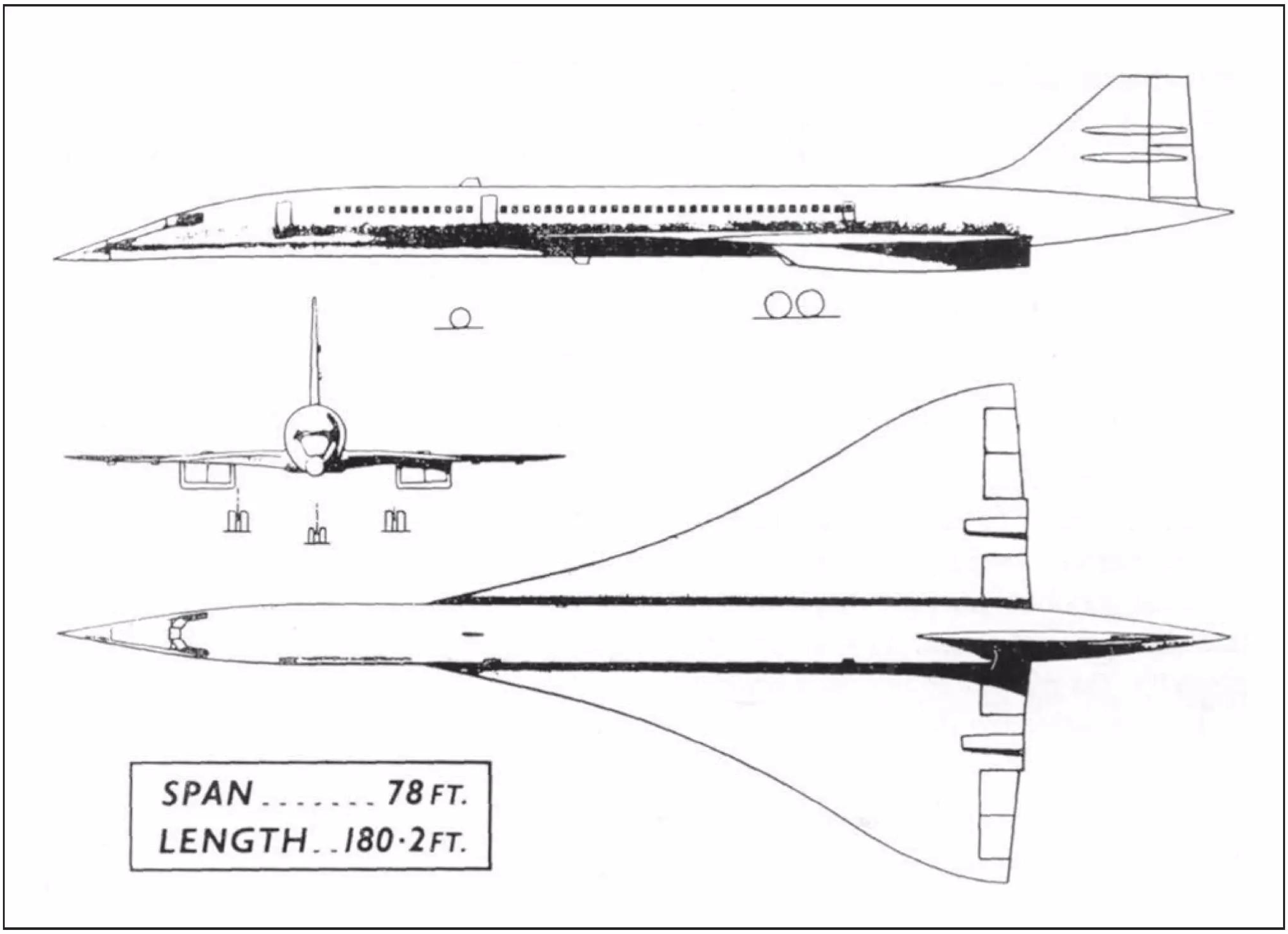
On 26 November the SST was referred to again at the French Senate, this time in respect of the budget of the civilian and commercial aviation. It was pointed out that the new class of supersonic aircraft would need new runways that could not be accommodated at Orly (then the main Paris airport) or Le Bourget, and so a new international airport would also have to be built (this became Charles de Gaulle Airport which opened in March 1974).

Then on 26 March 1962 Robert Buron for France and Peter Thorneycroft for Great Britain signed a declaration of intent on which to base further collaboration. On 25 May a quite optimistic internal note on the French side showed that the medium range aircraft was still the French goal, in that it referred to a Paris-Rome route flown in "less than 1 hour and 5 minutes… with such a gain offered to the airlines at nearly no cost, one cannot see why they would pass it by".

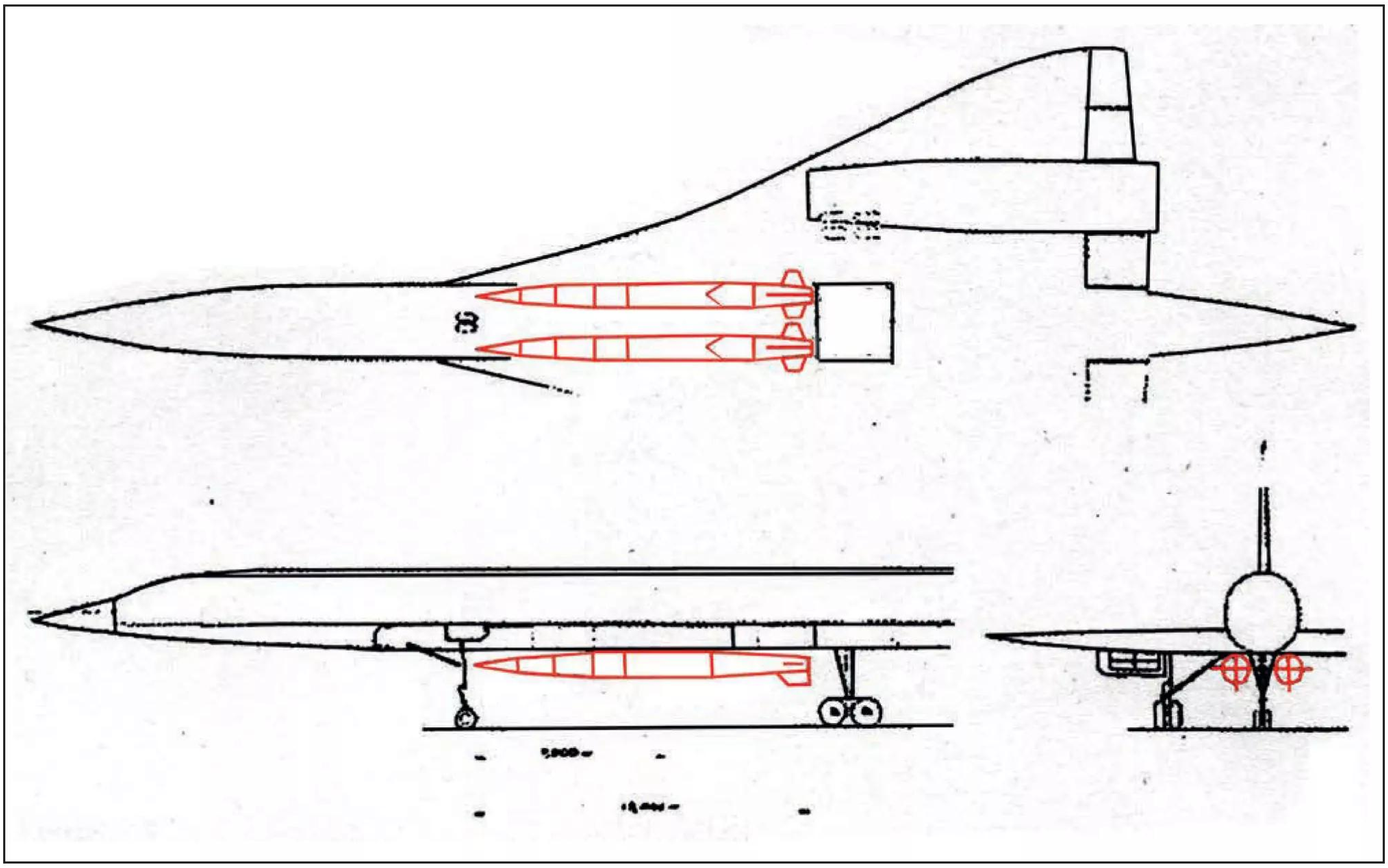
Héreil left Sud on 27 June 1962 because he opposed the proposed 50/50 workload ratio between France and the UK and the duplication of effort between the two countries aimed at the SST project. He was replaced by Général André Puget.

MILITARY SUPER CARAVELLE

One of the most secret projects in French aeronautical history remains the nuclear Minerve programme – which included a proposed version of the Sud Aviation Super Caravelle.



From a document published in 1963 but referring to an earlier design, this drawing still has a fixed nose but the windshield fairing considered since 1961 is there. The tail fin has also lost its trailing edge sweep and begins to look Concord-ish. *Sud Aviation via JC Carbonel*



In around 1962 consideration was given to using the Super Caravelle for military purposes. One option studied in the Minerve programme was to carry two X-414 ballistic missiles underneath the Super Caravelle, in which form it was called the PSS for Plateforme Super Sonique. *Sud Aviation via JC Carbonel*

In 1961 the Direction Technique et Industrielle issued a requirement for a ballistic missile with a range of 300km (186 miles) to be carried under a Mach 2-capable aircraft. On 1 October General Stehlin, Armée de l'Air Chief of Staff, wrote to the French Ministry of Defence about mothership/missile combinations and stated that "the Super Caravelle is the best solution from both technical and operational viewpoints". So, even before the go-ahead for the civil version had been given, the Sud project was already being considered in relation to the Minerve programme.

Industry was eventually requested to submit official proposals on 16 May 1962 and the missiles themselves were intended to be of two types, either a ground-hugging weapon or a ballistic version.

On 10 June 1962 Sud replied to the Call for Proposals with the X-416 and X-417 missile projects and with their mothership an adapted Super Caravelle. Sud had wanted to reuse the work previously done on the X-225 but this design proved too small to carry these large missiles. However, in the end it proved difficult to adapt the Super Caravelle to military needs, for example the aircraft's ogee wing was so well integrated with its fuselage that it would have been impossible to position a recess or bomb bay within it to house the weapon. This was unfortunate because the aircraft looked ideally suited for the role and the 9,000kg (19,841lb) missile would have weighed about the same as a load of passengers in the civilian airliner. With a go ahead given in July 1963 Sud estimated that its PSS (Plateforme Super Sonique, the name given to the military Super Caravelle) with two X-417s on board could be flying as a prototype by October 1967.

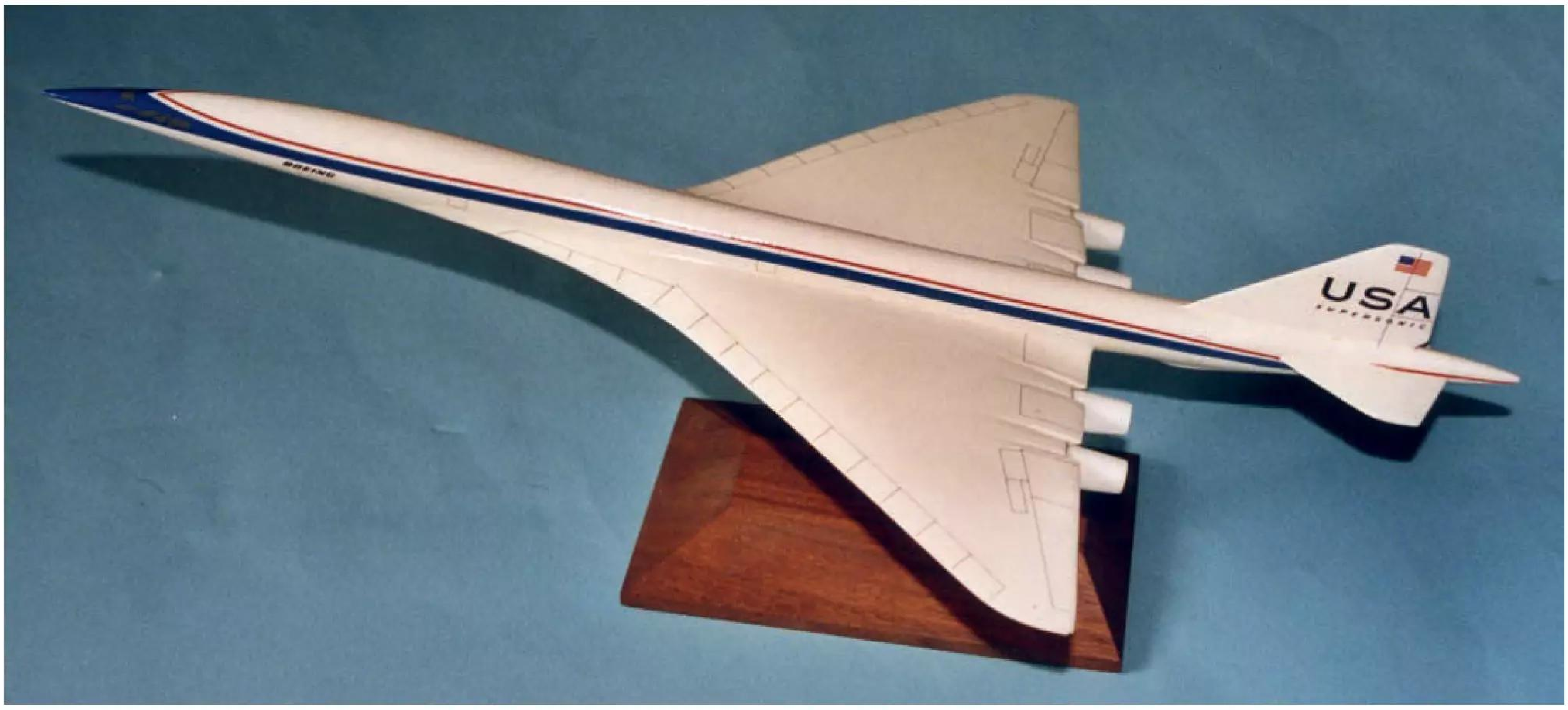
By November 1963 four final competing projects were under consideration, from Breguet, Dassault, Nord and Sud (the PSS), but then on 14 January 1964 French Président de Gaulle signed Decree 64-46 which created the "Forces Aériennes Stratégiques". This was to be equipped with Dassault Mirage IVAs fitted with an in-flight refuelling probe. As a result Minerve was abandoned.

SUPER CARAVELLE SELECTED

Despite looking so similar to the Concorde, the Super Caravelle IIID still needed a lot of development work – for example finding the definitive wing tip shape, refining the engine nacelles and the engine nozzles, refining the nose shape (at least three different forms were assessed before the variable geometry droop nose was confirmed), detailing the avionics, and even designing the air conditioning for the passenger cabin. But, after having been favoured on the French side, the combined Anglo-French team took the Sud Aviation Super Caravelle design as its basis. ◆

4

The American Scene



Model of the final fixed-wing Boeing Model 2707-300 SST. *George Cox*

Concorde was of course an Anglo-French project, but before the joint agreement was established with France the UK did negotiate with the Americans regarding a possible joint SST programme.

During late 1959 and early 1960, the Civil Aeronautics Board, a US Government agency, had become increasingly concerned about the possibility that a supersonic transport aircraft might be developed during the next few years by a foreign manufacturer. The board had, therefore, evaluated the present posture of supersonic transport development in the US.

It reported on 1 February 1960 that various American manufacturers' studies had indicated that if the supersonic transport came into being within the next decade, the entire requirement of all of the world's air carriers could be met by the manufacture of no more that 100 to 200 such aeroplanes.

Such a type would travel at 2,000mph (3,220km/h), carry 80-160 passengers and make travel to such points as Rome, Paris, or Frankfurt possible in around two hours. The economic cruising altitude would require the aircraft to fly so high (55,000-75,000ft or 16,765-22,860m) that economic utilisation would be improbable at distances of under 1,200-1,800 miles (1,930-2,895km).

Therefore, predominantly short-haul carriers would probably not operate it. American manufacturers were concerned that at least two foreign nations already building long range jet aircraft appeared ready to subsidise the development of a supersonic transport.

It was understood that both Britain and Russia had set a target to have an operating supersonic air transport entering service between 1965 and 1968.

Obviously, if a successful supersonic transport were developed by any country, many of the foreign international carriers who competed with the American civil industry would acquire the new type, and it would naturally follow that in order to stay alive over competitive international routes the American international carriers would be forced to buy that transport rather than to wait a few years for a competitive American type to be produced.

It seemed likely that every long range carrier in the world would want to acquire an SST and the board was concerned that a delay on the part of US manufacturers might result in America losing its lead in civil aircraft manufacturing.

The board report added that any of the four large American manufacturers of commercial transport aircraft would be capable of manufacturing such an aircraft given proper financial encouragement – since each had already carried out its own SST studies.

In addition North American Aviation, essentially a military contractor, had also spent a tremendous amount of time and money in the development of supersonic military aircraft. Obviously these efforts would be helpful if that company decided to compete in the civil supersonic transport field. One of these American manufacturers had estimated that, given adequate financial assurances, it could have a prototype flying in about three years and, following extensive flight testing, could make deliveries in a further three years or so.

BRITISH APPROACHES

General Elwood Richard Quesada USAF, the first Administrator of the Federal Aviation Agency, recommended on 1 September 1961 that the US Government's Executive and Legislative Branches should consider the immediate establishment of a national programme for the development of a commercial supersonic transport aircraft.

The knowledge that the US was now considering its own SST had prompted the British to make approaches. Back in 1959, STAC had looked at having partners to help develop the SST and Hawker Aircraft had had talks with Lockheed. In 1960 BAC Bristol was talking to Boeing, Douglas and General Dynamics (Convair), and then on 8 September 1960 discussions took place between British Ministry of Aviation officials and General Quesada. Here it was agreed in principle that co-operation in the development of a supersonic transport aircraft could be of mutual advantage.

A meeting held in the office of British Controller Aircraft (CA), Sir George Gardner, on 20 September 1960 took stock of the general situation. The only American present was E. I. R. MacGregor of the Civil Aeronautics Administration (CAA) who was visiting the UK at the time. It was also proposed that further discussions at Government level should take place in the New Year.

But Gardner considered that Quesada's readiness to collaborate on SSTs might extend only to marginal aspects such as air traffic control and noise. So far as the British input was concerned, Quesada's thoughts did not seem to go beyond the possibility of using a Rolls-Royce engine with perhaps some other British equipment.

Later on Gardner met further US representatives, including John Stack from the Langley Research Center who much earlier had been involved with the Bell X-1, which in 1947 had been the first manned aircraft to achieve supersonic flight. Gardner explained that UK opinion was at the moment definitely in favour of a light alloy aircraft and attention was being focused on this, but without abandoning all work on the higher speeds.

Stack replied that he was extremely hesitant about using light alloys when so little was known about their fatigue life under the conditions they would experience in supersonic transport operations. Considerable information would be obtained from the steel/titanium XB-70 before the SST entered service and no similar background of flying knowledge would be available for a light alloy supersonic transport.

There was, therefore, always the risk of some unexpected disaster occurring, such as had hit the Comet aircraft during the mid-1950s. Stack added that the US view was that a variable geometry wing was the only possible solution for speeds of Mach 2.5 and above. He also said that practical Mach wave tests made using Convair B-58 bombers had indicated that flights over land at supersonic speed would have to be made at heights above 45,000ft (13,716m), but more work needed to be done.

On 27 October 1960 the UK Minister of Aviation wrote to Richard Quesada inviting the Americans to join in the British Mach 2.2 study with the option of sharing in the project if it were agreed that it should go ahead. In return the UK should expect a chance to share in a Mach 3 project, if that were decided upon instead. Quesada's acknowledgment merely stated that this proposal would be given the fullest consideration and that a reply would not be easy.

On 18 January 1961 BAC Bristol's designer Dr Russell met British Ministry officials and E. I. R. MacGregor in Washington to discuss co-operation with France and the USA. McGregor outlined the position in the USA. It seemed most probable that the US would concentrate on a steel aircraft, not necessarily Mach 3, for a number of reasons. Quite apart from the technical arguments advanced to support this, and the fact that the XB-70 programme could be a useful basis for the development of a steel airliner, there was the need for prestige reasons to outdo or at least match what other nations were thought to be trying to achieve.

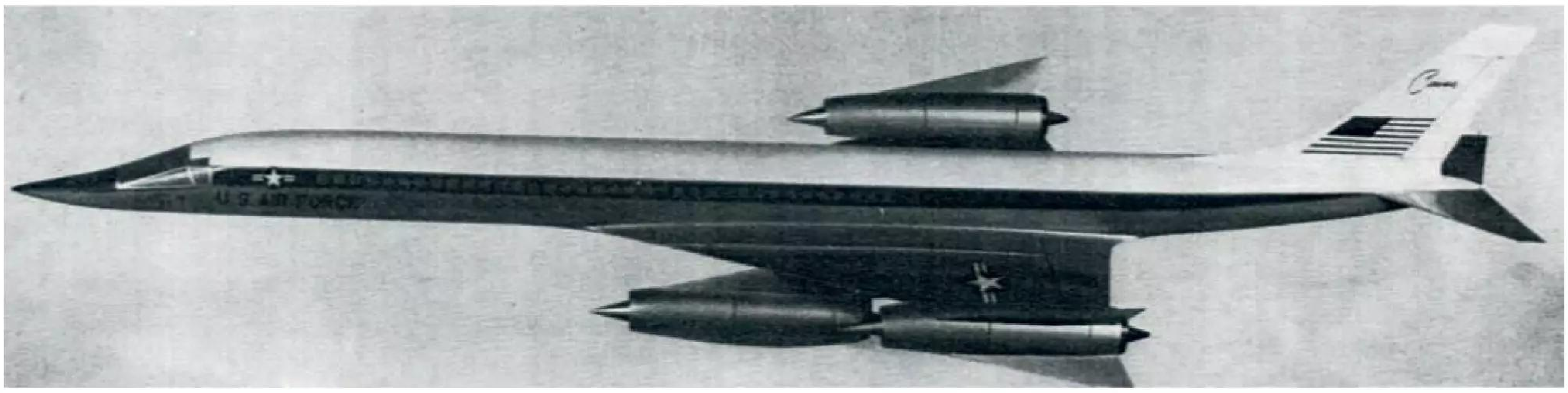
The possibilities of collaboration therefore seemed remote if the UK persisted with a Mach 2 light alloy project. In addition, the American firms seemed reluctant even to co-operate with each other, let alone a foreign competitor.

Russell did not think that a direct approach from BAC to any American firm would be of any use; in fact BAC did go on to make approaches to American firms, but without any success. In May 1961 BAC head Sir George Edwards discussed the matter with Najeeb Halaby, second Administrator of the Federal Aviation Agency (FAA), and offered to share all of the information on the Mach 2 studies, but Halaby replied that he could not see what useful purpose this would serve. Edwards also reported the Boeing view that they could not see any need for collaboration either inside the USA or outside it.

AMERICAN SET ON MACH 3

A BAC memo from 6 July 1961 noted that the FAA was apparently strongly in favour of Mach 3+ and for the time being this was having a strong influence on manufacturers anxious to win the contract. In response to approaches to explore possible collaboration with the UK, all the American manufacturers had been polite but negative and unenthusiastic.

The memo concluded that within 2-3 decades the bulk of long distance passenger travel would be at supersonic speeds and Britain could not let itself be edged right out of the supersonic transport field by America and Russia. Also, the UK held a 2-3 year lead over the US in considering SST issues, with the US having only just established its STAC equivalent. The UK had dismissed the Mach 3 steel/titanium design – since it would taken a long time to perfect – but the Americans were set on pursuing exactly that.



Convair 58-9 model.

Evidence suggested that the US intended to cash in on military experience gained from the XB-70 but was thinking in terms of variable sweep wings. Like the UK, the US had rejected VTOL.

The British were by now convinced that they had evolved a supersonic transport design which could be attractive to passengers and be more profitable to operate than any transport likely to evolve from this American line of thinking.

By November 1961 the prospects of collaboration between the US and the UK were over. Some thought had been given to the idea that the project should consist of an American airframe and a British engine, but both the UK Government and Rolls-Royce were very sceptical as to whether the American Government could really sustain a decision to adopt a British engine, this in the face of the powerful 'aero-engine' lobby that existed in the US.

In any case, in the long-term Britain's industry would be gravely weakened unless British manufacturers played a substantial part on the airframe as well as on the engine side. There were, however, still a number of subsidiary though important fields in which co-operation with the United States would be desirable, for example with studies into the 'sonic bang' problem and with certification.

It was considered extremely important that both Governments should keep in close touch on the question of such standards as noise, traffic control, airfield restrictions etc., for the project. Unless these were agreed internationally beforehand and firmly adhered to, the success of any particular SST project would be very much at risk.

With this clear diversity in objectives the British effort to establish full collaboration with America had come to an end. It now moved towards collaboration with France.

THE AMERICAN SST

In June 1963 the US officially launched its SST programme with a 'Phase One' Request for Proposals to Boeing, Lockheed and North American, with contracts to be awarded in 1965 or 1966. A short list for 'Phase Two' SST studies was made in May 1964 and at this point North American dropped out. Eventually, on 31 December 1966 Boeing won the contract to produce the American SST. In spite of opposition in regard to the aircraft's technical requirements, and its economic viability, the project had garnered strong backing from the FAA and from American industry. And a major shot in the arm had been provided by Pan American Airways who in May 1964, and with the intention of being the first American airline to become 'supersonic', had placed options to buy six Concordes.

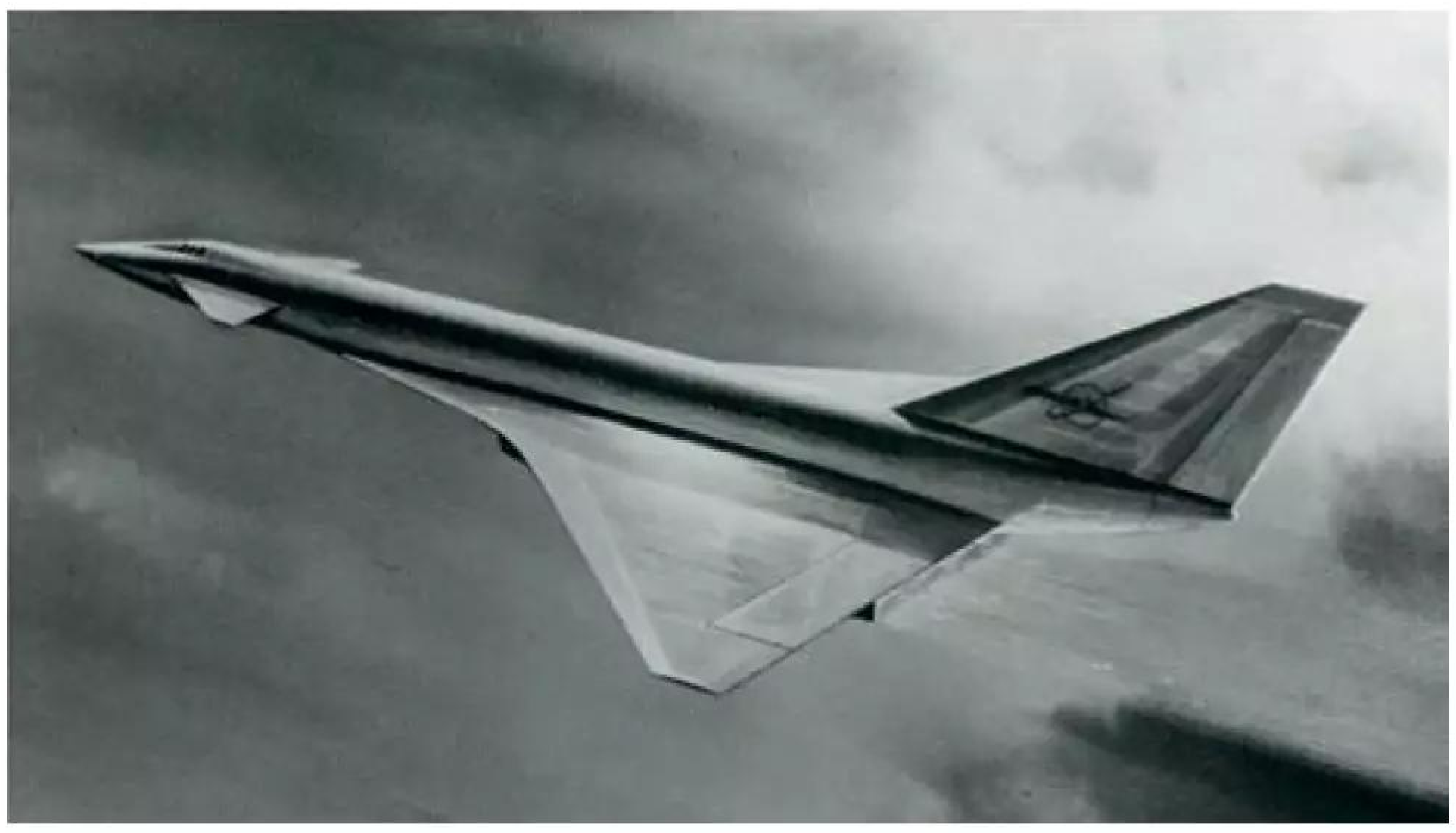
It is worth reviewing a selection of the American SST projects which led on to the final proposals and the resulting Boeing SST programme. The designs listed here are by no means comprehensive or complete, but they do give an idea of just how much work was done across the US.

CONVAIR 58-9

In 1960 Convair was looking at a three-stage programme for a supersonic airliner: 1. Simulated airline operational testing using a B-58 Hustler. 2. Fitting a 'people pod' beneath a Hustler to explore the human reaction to supersonic transport flight. 3. Building 12 examples of a B-58 transport version called the 58-9, the first of which could fly in October 1963.

The 58-9 medium-haul Mach 2.4 52-passenger airliner would have a 2,525nm (4,679km) range. It was to be powered by four 33,000lb (146.7kN) dry thrust P&W J58 engines. Take-off weight was 190,000lb (86,184kg) for a field length of 6,500ft (1,981m). The 58-9 was based on the proposed B-58C bomber development, but the American magazine *Aviation Week* reported that "by Convair's own admission

This model of the Douglas Model 2229 portrays the aircraft in cruise configuration, with the wing tips angled downwards.

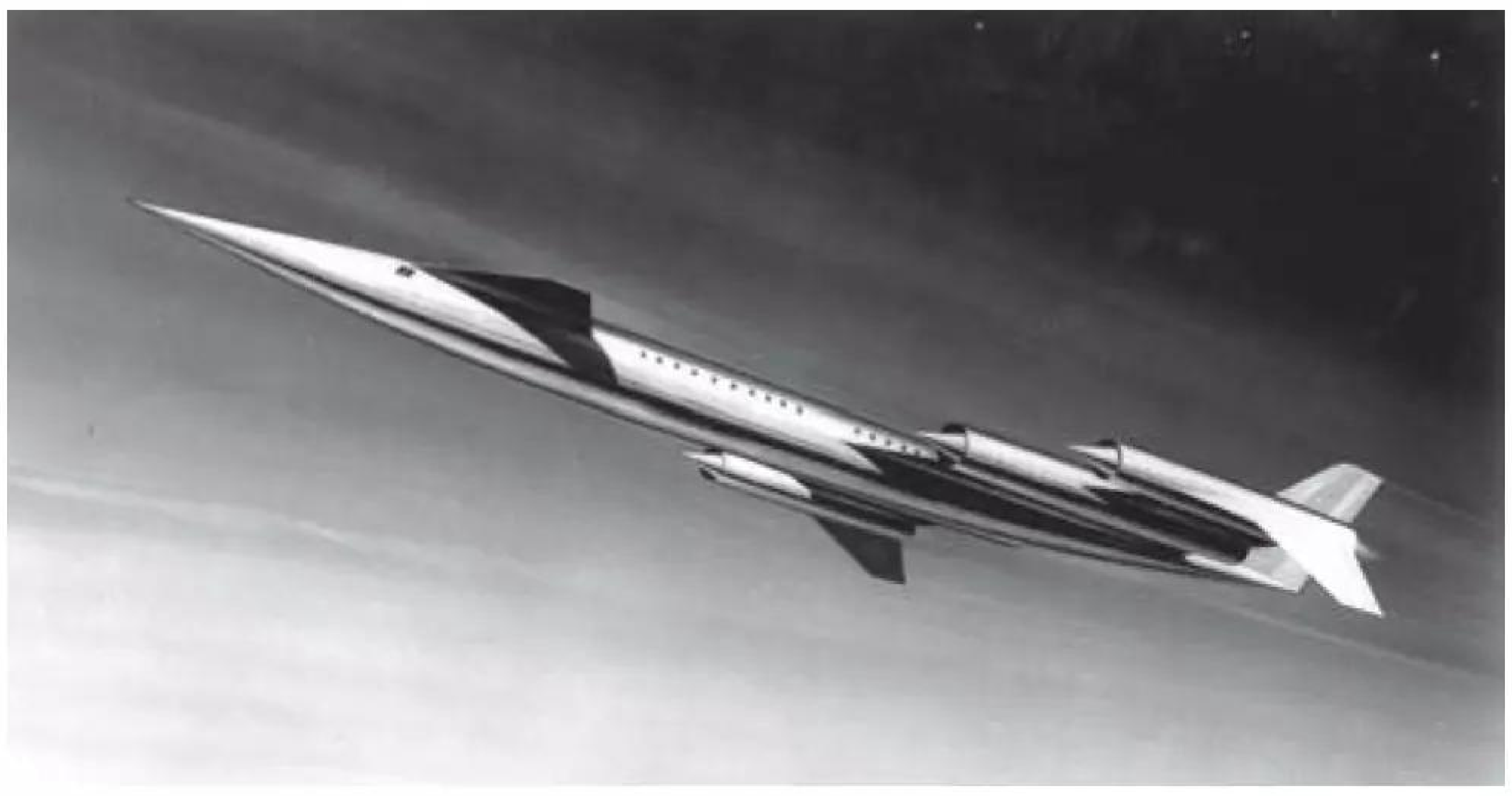


Artwork showing the Douglas 2229 in flight.

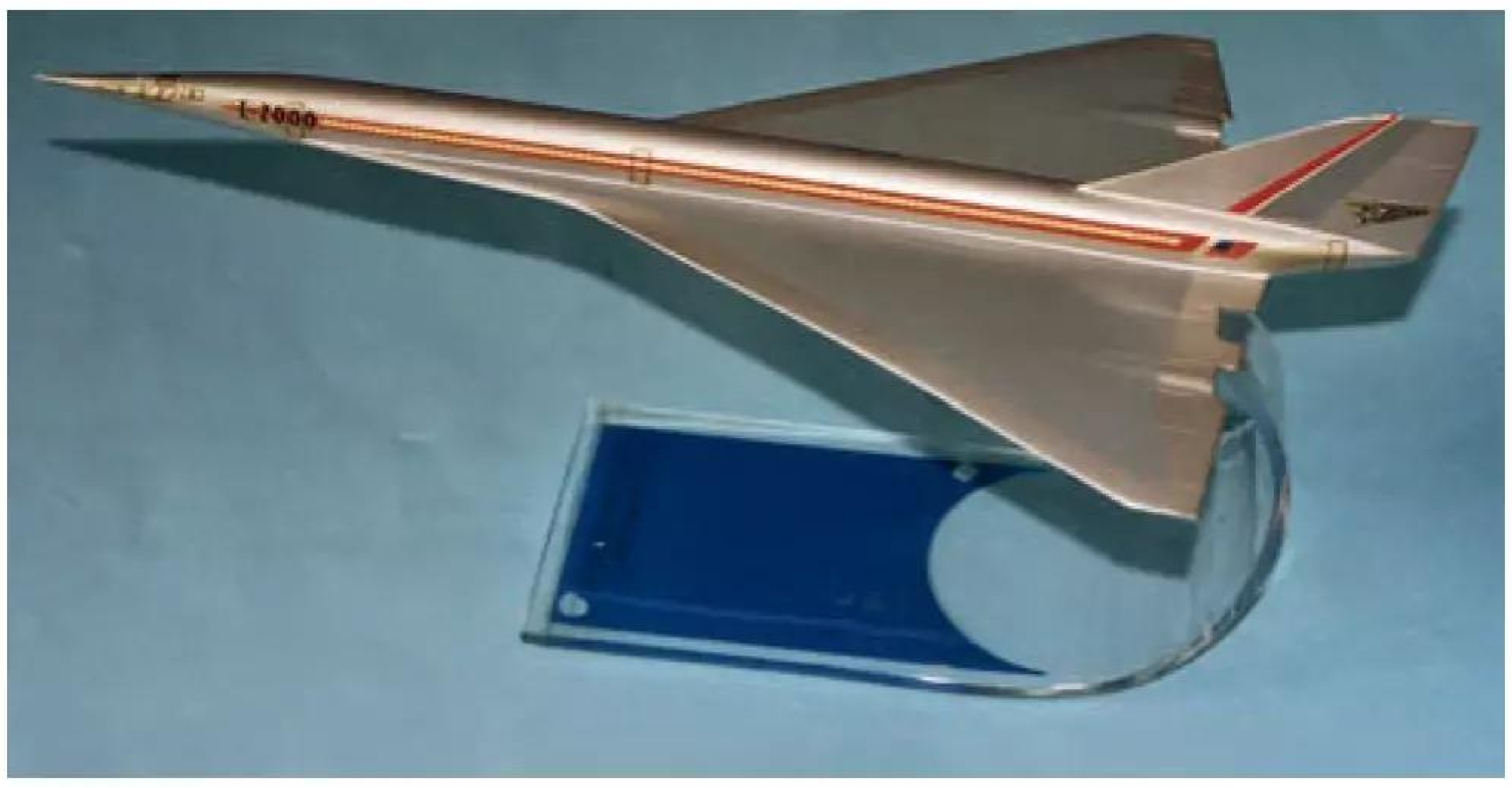
Mach 2.4 is the wrong speed for a supersonic airliner". The Convair brochure had based its programme on the assumption that an order to go ahead would be given in January 1961.

DOUGLAS MODEL 2229

Flight magazine of November 1961 reported that Douglas Aircraft thought the next generation of airliners should cruise above Mach 3. Although lacking the finance to design and build such an aircraft, Douglas had by this date nonetheless conducted extensive studies into a transatlantic 130-passenger 200ft (61m)-long Mach 3 design called Model 2229. Wingspan with tips fully spread was about 100ft (30.5m) and gross weight was 400,000lb (181,440kg). In order to raise the cruise lift/drag ratio, at full speed the outermost 20ft (6.1m) of each wing would be folded downwards. Four turbojets were mounted at the rear of an inlet-duct box which extended forwards to the leading edge of the wing on each side of the aircraft and these had two-dimensional intakes. During flight the front windows would be faired off.



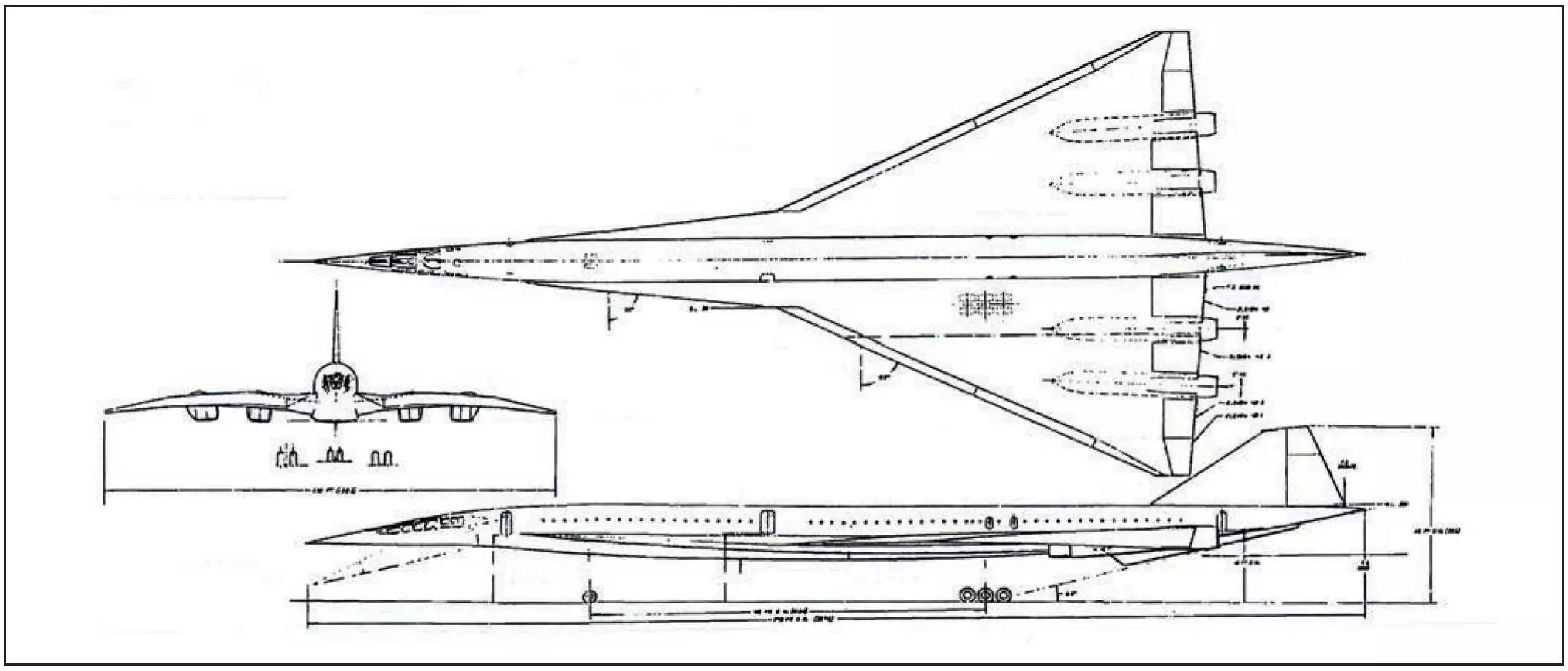
Artwork depicting a currently unknown SST from Lockheed. *Wolfgang Muehlbauer*



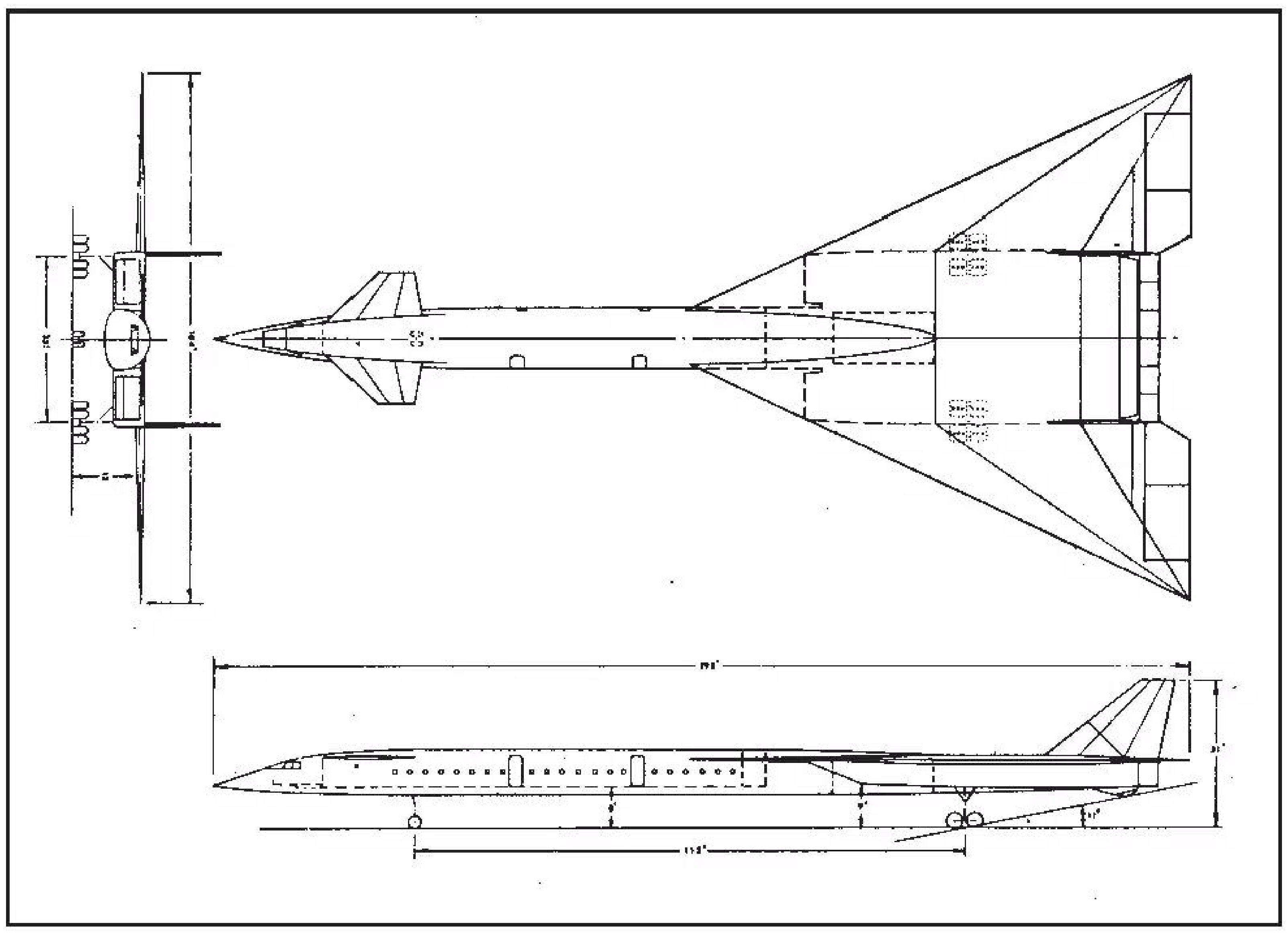
Original manufacturer's model of the Lockheed CL-2000, now labeled L-2000. Both Boeing and Lockheed built huge full-size mock-ups of their SST designs. *George Cox*

LOCKHEED CL-823 AND CL-2000

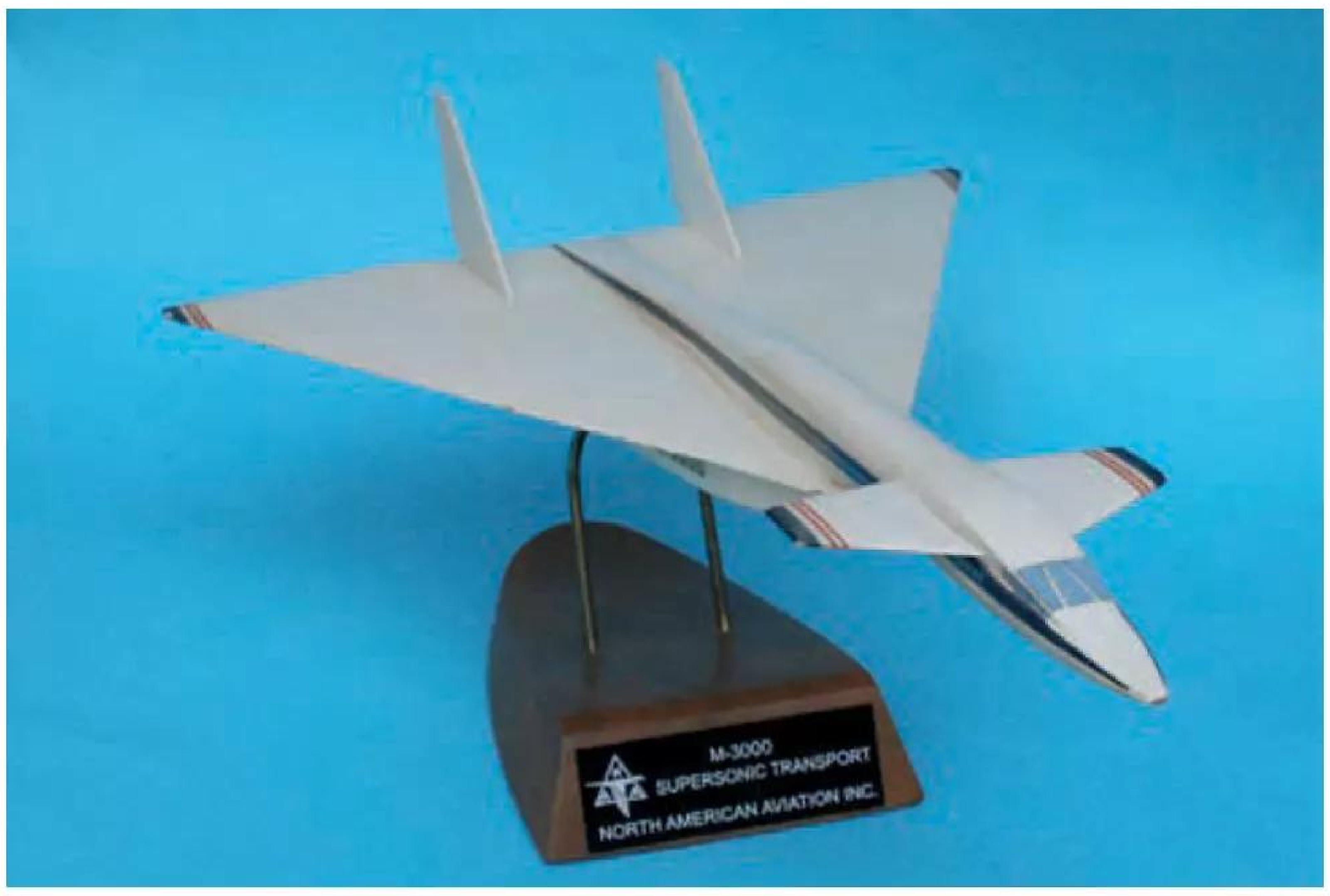
Way back in January 1957 *Flight* magazine had reported that Lockheed was working on a Mach 2.7 project. Lockheed's official entry in the SST race was initially designated CL-823, but between 1963 and 1966 this project number covered at least 43 design iterations. The effort was subsequently reassigned as the Mach 3 CL-2000 and a full-scale mock-up



Three-view general arrangement drawing of the Lockheed CL-2000 fitted with General Electric Engines. The Pratt & Whitney variant did not have engine jet pipes extending beyond the wing trailing edge. *Peter Clukey*



Three-view drawing of North American's 'Typical SST' project of June 1961.



Manufacturer's model of the North American M-3000 SST which was based quite closely on the XB-70. *George Cox*

was built. There was also a brief study into another Mach 2.7 SST under the CL-980 designation.

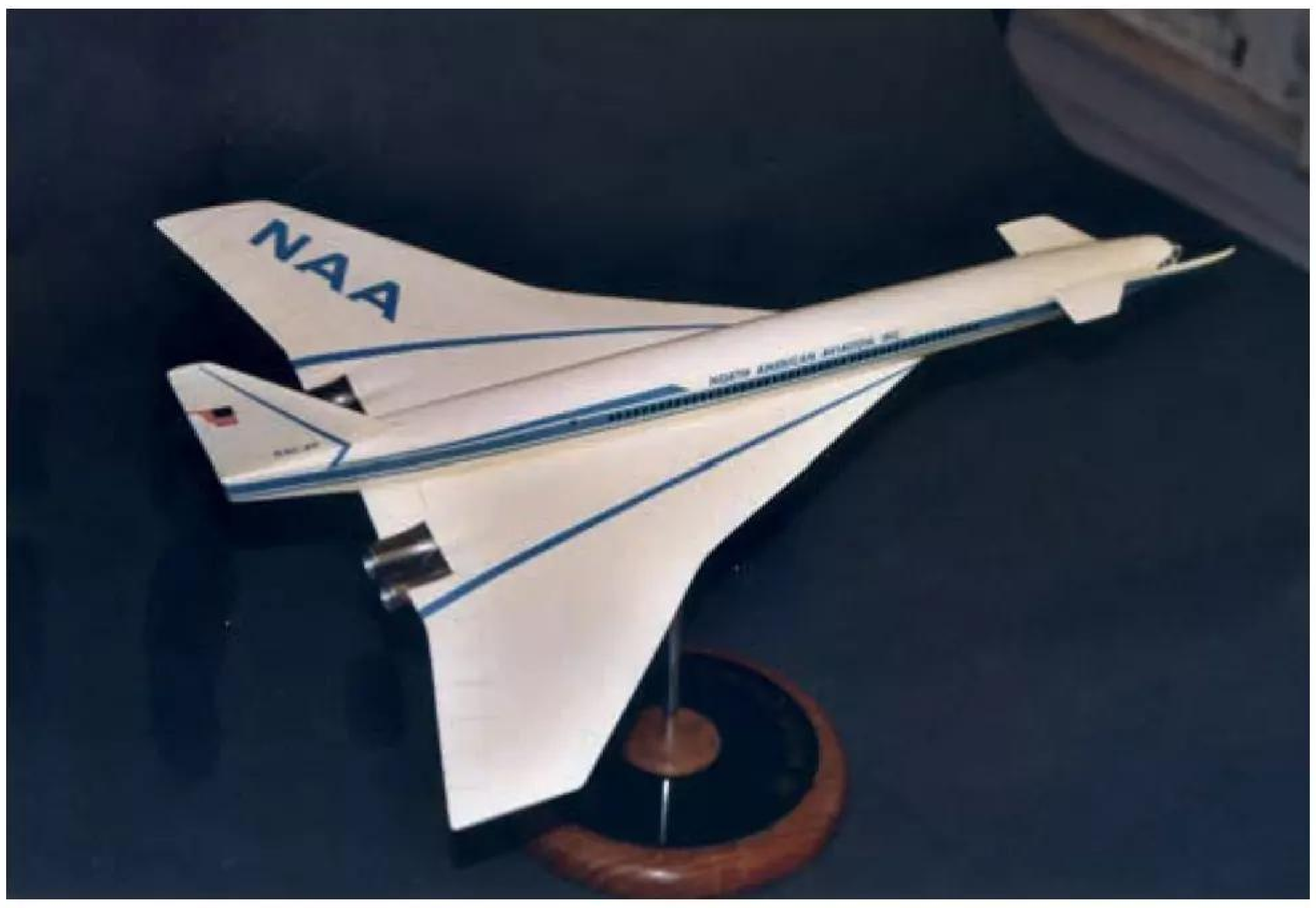
The CL-823 featured a long slim fuselage, a compound/double delta wing and engines mounted beneath the wing in separate boxes. There was a complete lack of any form of high-lift devices for the wings, so engine power and long runways alone would have to suffice to complete a lift off, which would mean plenty of noise. The aircraft would have carried about 218 passengers, its span was 116ft (35.36m), length 222ft (67.67m), wing area 8,000sq ft (744.00sqm), gross weight 450,000lb (204,120kg) and cruise speed Mach 3 at 70,000ft to 80,000ft (21,336m to 24,385m).

The definitive CL-2000 (later L-2000) with its double-delta wing, and a configuration overall which was quite similar to the Concorde, was submitted to the FAA in 1966. There were two versions, identical except for their engines – either the General Electric GE4/J5M or Pratt & Whitney JTF17A-21L and with similar performance from each. Passenger capacity was 258-273, cruise altitude was 70,000ft (21,336m) and normal range 4,000nm (7,410km). Wingspan was 116ft (35.36m), length 273ft 2in (83.26m) and wing area 8,846sq ft (822.68sqm). Gross weight was 590,000lb (267,624kg). Although Mach 3 was quoted it is understood that Mach 2.7 was the declared cruising speed. Wing sweep-back angles were 84° inboard and 65° outboard and the engines would be mounted in individual pods along the wing trailing edge. A 15° droop nose-cone would provide a clearer view for the crew during take-offs and landings.

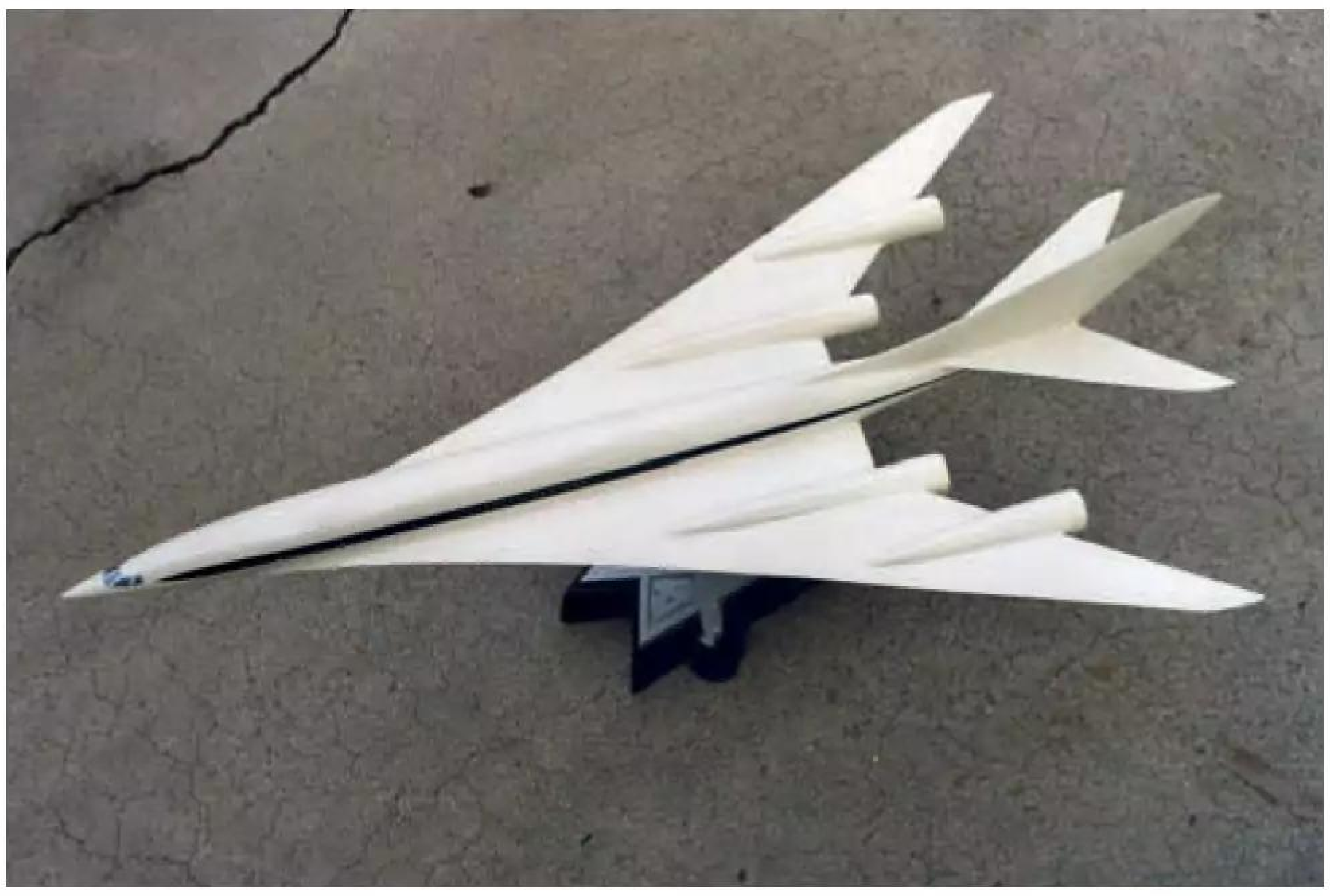
NORTH AMERICAN 'B-70 STUDY' AND NAC-60

North American Aviation produced its XB-70-based SST in June 1961, even though the XB-70 itself was still some way off its first flight at this point. The firm's Supersonic Transport Study Group based at Los Angeles had completed a report which contained a performance summary and layout for a "Typical Mach 3.0 Supersonic Transport".

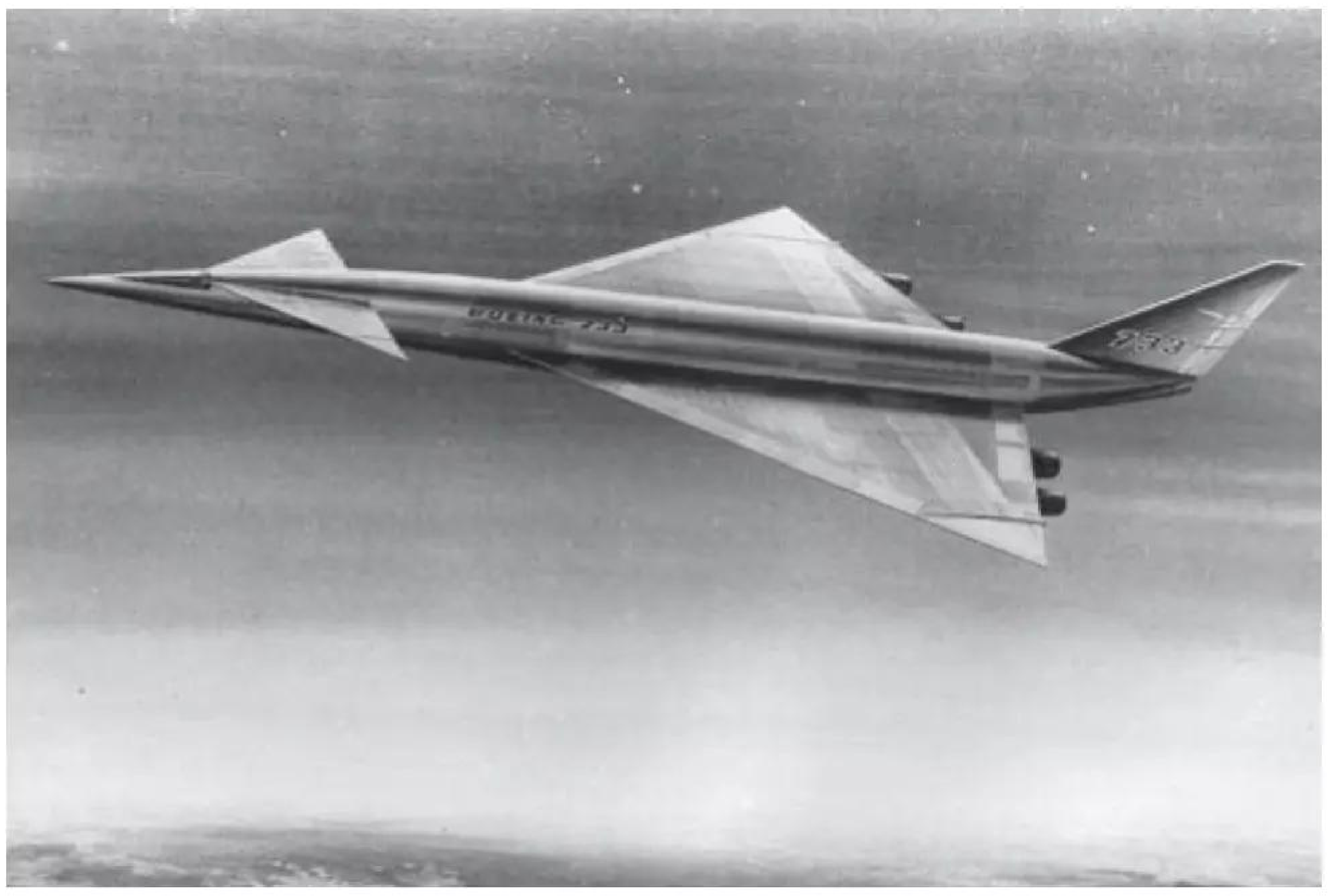
An intensive but general 'Supersonic Transport for the 1970s' programme and parametric studies had now allowed this preliminary definition of a configuration to be made, together with the performance, weights and operating costs that might be possible. However, this did not represent



Manufacturer's model of the NAC-60, North American's main entry in the SST contest. It retains a number of XB-70 features, most notably the high-mounted canard foreplane. A model of this design, along with a smaller study featuring a variable-geometry wing, was displayed at the Paris Air Show in June 1963. *George Cox*



This alternative North American SST study model features a swept wing and widely-spaced wing-mounted engines. *John Aldaz*


Artwork for an early Boeing Model 733 concept with a delta-type wing.

Promotional model made by Boeing of the variable geometry Model 2707 SST in BOAC colours. *George Cox*

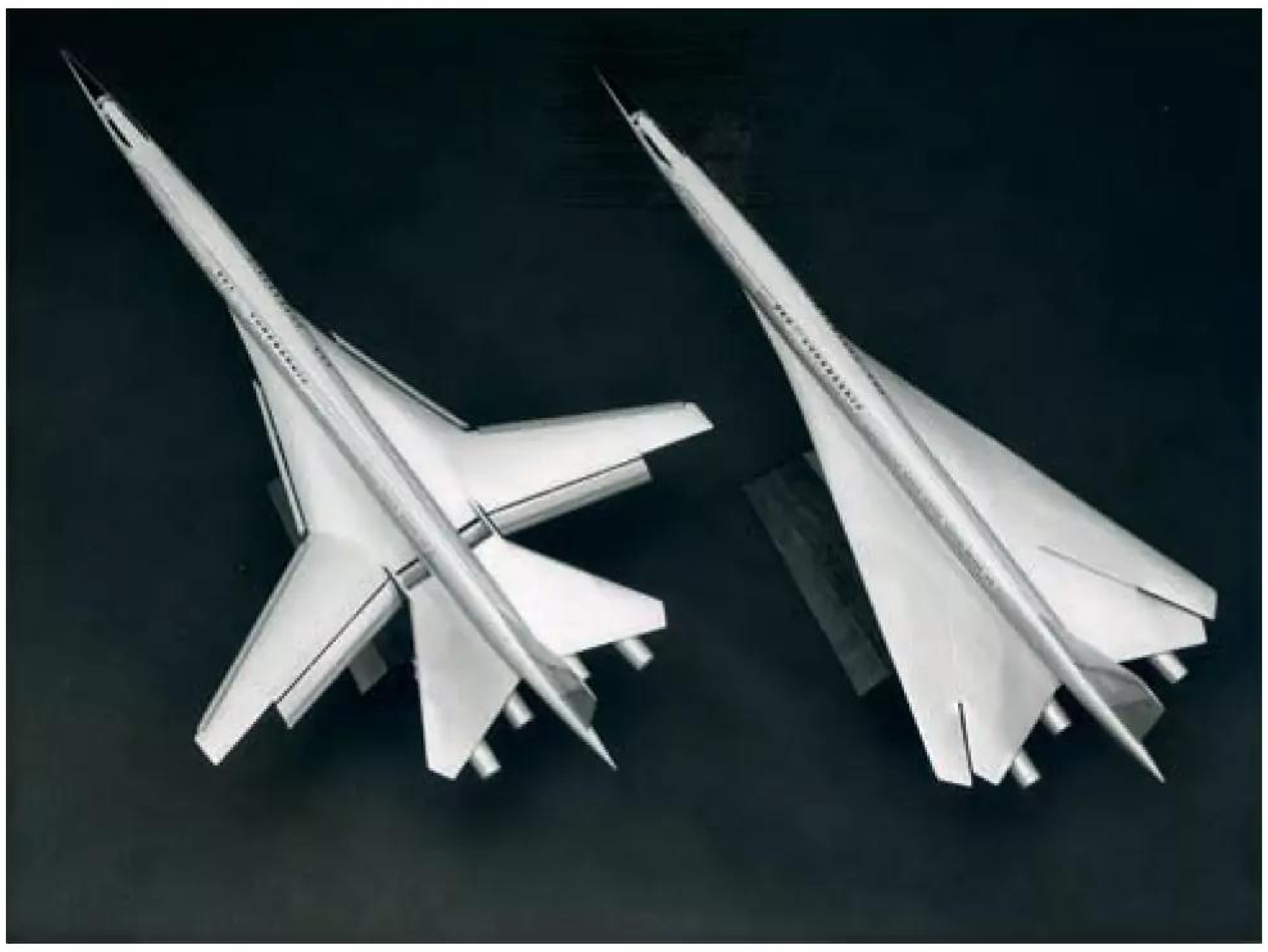
a firm design proposal because many other possible configurations were still under study.

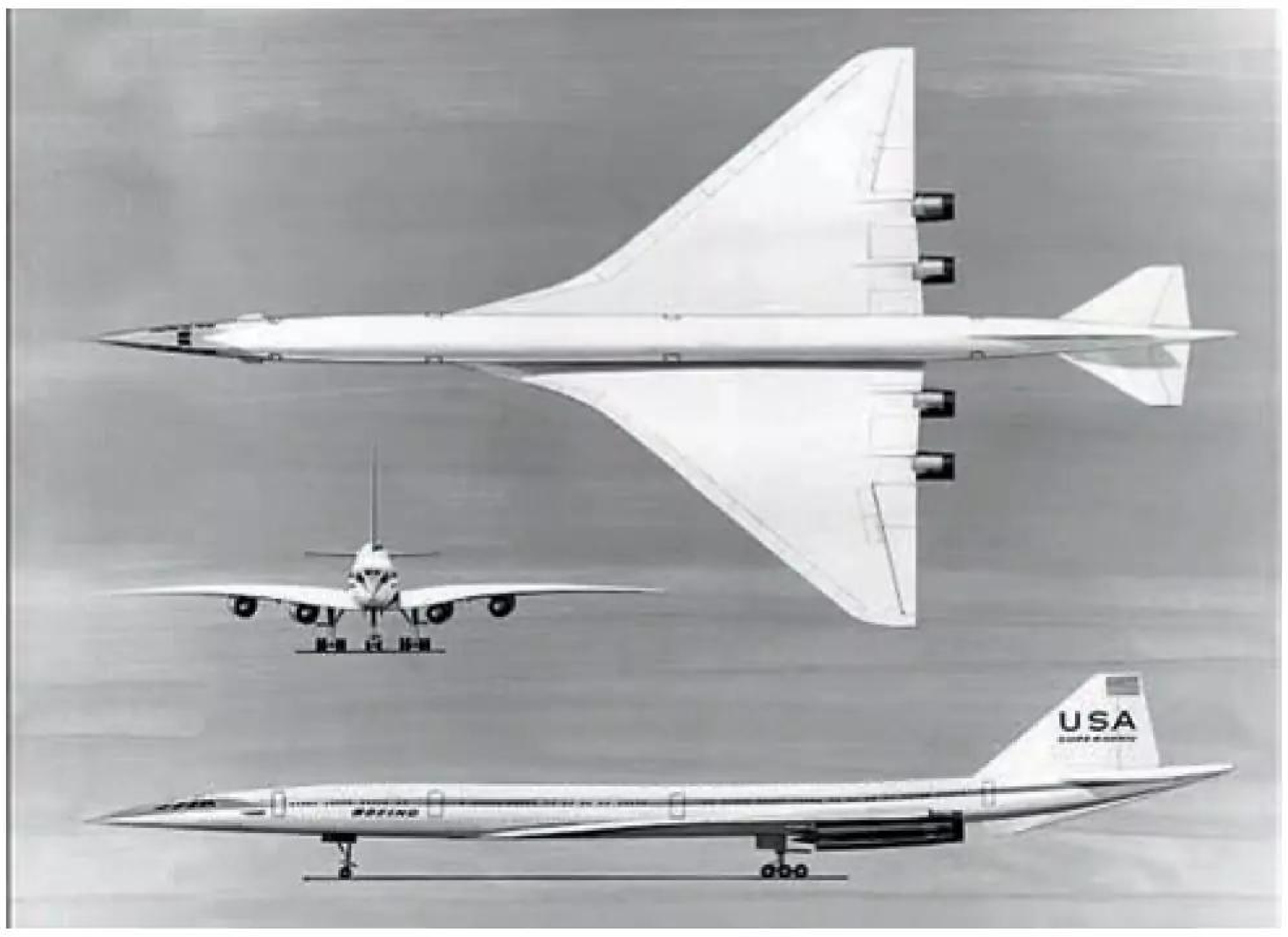
As it stood, this 'XB-70 Variant' was to be built of brazed stainless steel honeycomb sandwich and riveted titanium sheet construction. It had a trimmable canard foreplane, folding wing tips to help provide efficient cruise at supersonic speed, spoilers and speed brakes. Six 31,000lb (137.7kN) thrust duct-burning turbofans, each fitted with a thrust reverser, would provide power and a multi-shock air intake arrangement would feed each set of three engines. Span was 104ft (31.70m), length 198ft (60.35m), wing area 7,000sq ft (651sqm), wing leading edge sweep angle 65.67° and on the canard 38°, and the canard area was 410sq.ft (38.1sq.m).

Passenger capacity was 124 with maximum gross take-off weight of 439,000lb (199,130kg). After take-off, the aircraft would make a subsonic climb to about 43,000ft (13,106m) (a figure dictated by sonic boom ground overpressure) and then begin a transonic acceleration and climbing acceleration to Mach 3 up to about 70,000ft (21,336m). Soon afterwards North American suggested using an XB-70 as an SST Technology Demonstrator (the XB-70 itself flew on 21 September 1964 but never went into production).

The company also produced another project based on the XB-70 called the M-3000, for which a full-size mock-up was built. However, North American's main SST proposal was to be the NAC-60 which featured a new compound-delta wing with high-lift devices (double slotted flaps) plus an all-movable trimming foreplane canard mounted high on the fuselage just aft of the cabin, items which made a 'droop nose' unnecessary.

To increase the lift-drag ratio, the wingtips would fold down during cruise at high Mach numbers and initially the NAC-60 was designed to cruise at a maximum of Mach 2.65, although the design provided for further development to Mach 3 should this prove necessary. The aircraft's four engines were mounted in underwing nacelles in boxes of two; they had spiked half-annular inlets and the problem of counteracting yaw following an engine failure at supersonic


Two scale models of the Boeing 2707-200 SST with variable geometry wings. The left hand model shows the subsonic configuration with wings set forward and the flaps fully deployed to provide extra lift. The right hand model has the aircraft as it would appear in supersonic flight with the wings fully swept back to an angle of 72°. When fully swept the wing was integrated with the large tailplane to form a single lifting surface. Note the area-ruled fuselage and the engines mounted right aft. *US National Archives*



Three-view drawing of the Boeing 2707-300.

From December 1962 North American A-5A Vigilante serial number 147858 was used by the NASA Flight Research Center to establish the "let-down and approach conditions" for an SST flying into a dense network of air traffic. The trials flying lasted for a year before the Vigilante was returned to the US Navy on 20 December 1963.

speed was solved in part by having the engine thrust lines inclined inwards. The principal structural material was to have been titanium and the maximum passenger capacity was given as 187. Span 121ft 4in (36.98m), length 195ft 5in (59.56m), wing sweep-back angle 65° inboard and 50° outboard, maximum weight 480,000lb (217,728kg), range 3,900nm (7,225km).

BOEING MODELS 733 AND 2707

Boeing began some research into small-scale SSTs in 1952, and then in 1958 established a permanent research committee to assess a variety of alternative designs under the Model 733 designation. Most of these used a large delta wing, but in 1959 a version appeared with a variable geometry wing and this was the format adopted by Boeing for its future proposals.

The original competition entry was the Model 733-197 for 150 passengers and this project's four engines were mounted in individual nacelles. Its span was 173ft (52.73m), span swept 86ft (26.21m), length 175ft (53.34m), gross weight 430,000lb (195,048kg), cruise speed Mach 2.7 at 65,000ft (19,810m) and range 4,000nm (7,412km).

To illustrate Boeing's determination in this field, on 11 September 1961 BOAC in London was visited by a team from Boeing for a general discussion on SSTs. The resulting BOAC memo stressed that it was clear if there was to be a supersonic transport aircraft built in America then Boeing was determined to be the firm to build it. And Boeing was obviously a lot of its own money on the necessary research and development work to make it happen.

After a 1966 request for more detailed proposals Boeing produced the Model 733-390 with a structure in titanium and 300 seats. This was also called the Model 2707-200 and was 306ft (93.27m) long, which would have made this the longest aircraft yet built. It spanned 174ft 3in (53.11m) fully spread and 105ft 9in (32.23m) swept and was intended to cruise at Mach 2.7 over a range of 3,900nm (7,225km).

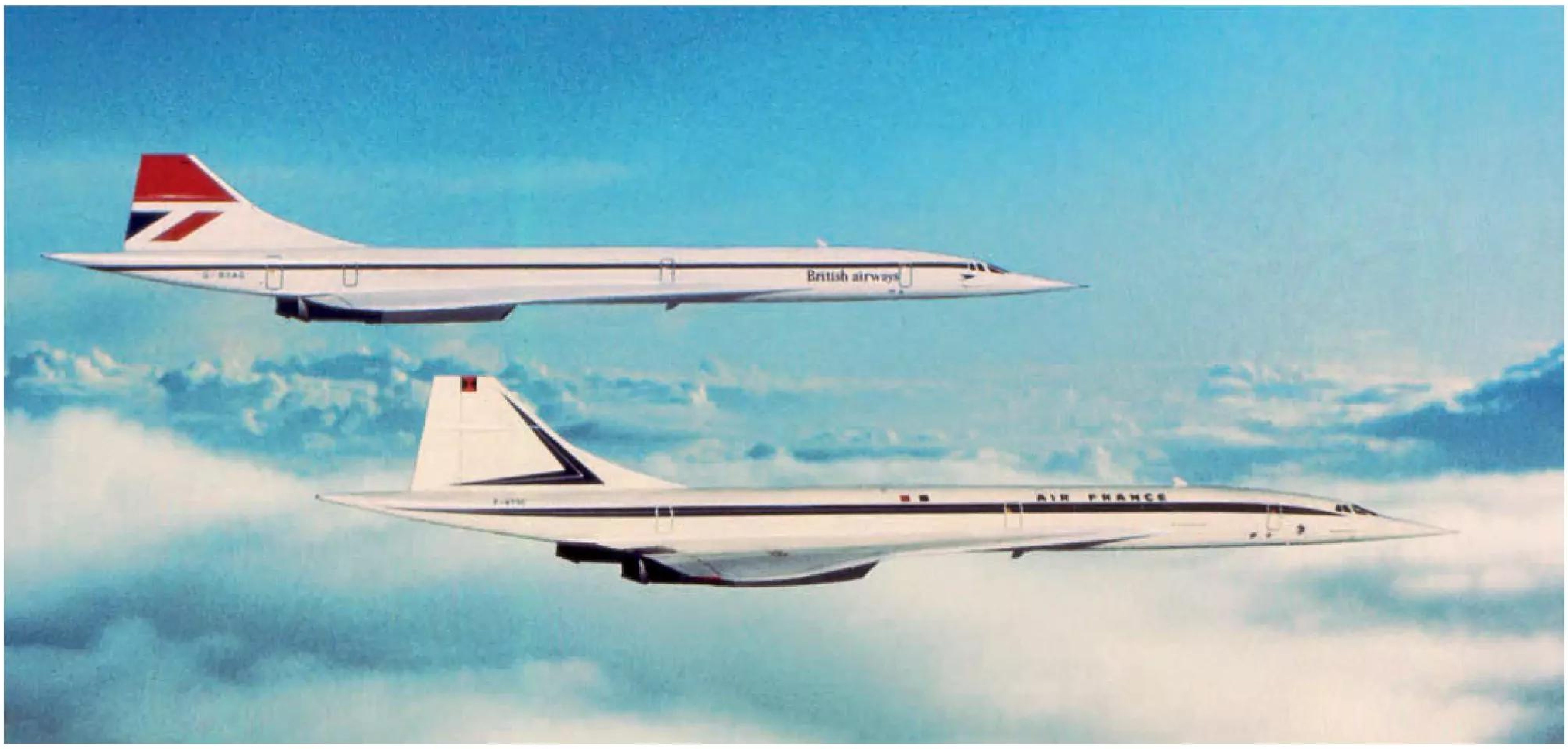
Boeing's submission was declared the winner over Lockheed on 1 January 1967 but the complexity of this swing wing design soon brought trouble, in particular with the hinge mechanism (which needed to be near the fuselage). There were big increases in weight and the aft-mounted engine arrangement gave poor mass distribution. The ongoing weight situation eventually made it clear that the aircraft would most likely carry too small a payload over too short a range. There was clearly no way forward and so in September 1968 the swing-wing Model 2707-200 was abandoned.

A review of possible alternative layouts eventually brought forth a more conservative fixed-wing delta design with a tailplane and separate engine pods, Model 969-302 – offered as the Model 2707-300. The tailplane was assisted by control surfaces on the wing trailing edge and four 67,000lb (297.8kN) thrust General Electric GE4 engines would push the aircraft up to Mach 2.7 at 73,000ft (22,250m). The 2707-300's span was 141ft 8in (43.18m), length 286ft 8in (87.38m), range 4,200nm (7,785km) and seating capacity between 250 and 321.

It was announced on September 23, 1969, that two prototypes were to be built for flight in late 1972 or early 1973, and in due course 26 airlines paid deposits in all on 122 airframes. However, the economic and environmental arguments which came to the surface during the early 1970s brought a halt to American SST funding in May 1971, and only the full-scale mock-up of Boeing's design was ever completed. ◆

Establishing a Joint Project

5



Publicity models from the 1970s showing production Concordes in both British Airways and Air France liveries (BOAC merged with BEA in 1974 to form British Airways). Had not France and the UK agreed to work together on the SST, then we might never have seen Concorde.

The negotiations to produce a joint project with the US had come to nothing, but collaboration with the other possible candidate – France – would of course prove more fruitful!

As noted in Chapter 3, the first official discussions in regard to a possible joint French/UK programme took place at the Ministry of Aviation in London on 27-28 October 1959. The UK delegation comprised Dr Walter Cawood (Deputy Controller of Aircraft Research and Development), Dr Drinkwater and Messrs. Hole, Meeres, Nicholson, Remfry and Templeton, while the French delegation was formed by Ingénieur General Geradin, Ingénieur en Chef (Chief Engineer) de Lagarde, Ingénieur en Chef Foch, Ingénieur Principal (Senior Engineer) Seguin and Ingénieur en Chef Vialatte.

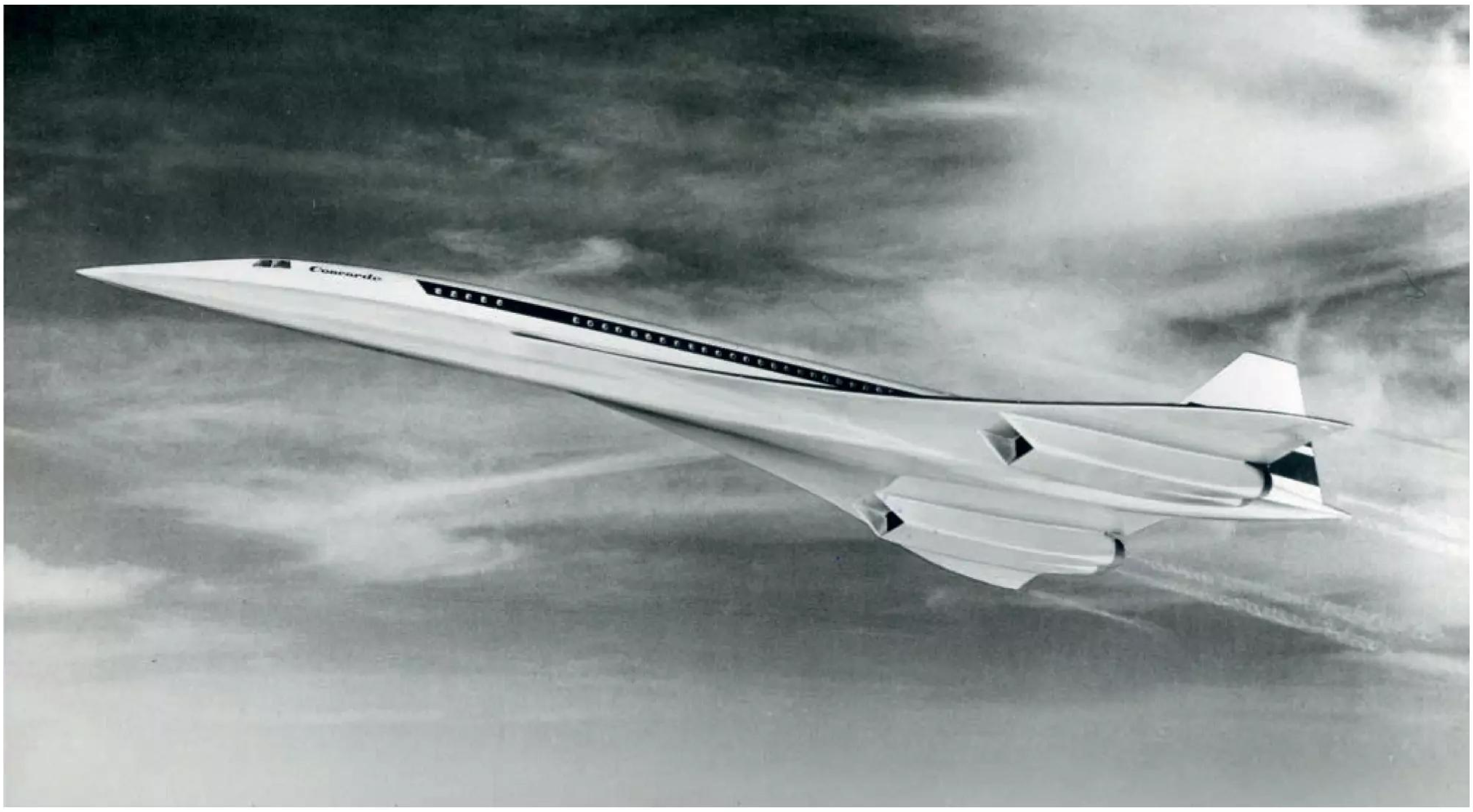
The UK representatives had outlined the country's efforts towards a supersonic civil transport aircraft, the work of STAC and how earlier in the year the committee had recommended that two aircraft should be developed: one for a medium range (1,500 miles/2,415km) and Mach 1.2 and the other for long (transatlantic) range and Mach 2.

Since then a more detailed investigation had suggested that a cruising speed of perhaps Mach 2.4 might be possible with a light alloy structure airframe, but the committee had concluded that Mach 3 was not a suitable objective for a first generation SST.

French policy up to now had been to concentrate on the medium range category of aircraft, a policy which had of course produced the Sud Caravelle. Three French firms (Nord, Sud and Dassault) had been asked for their views on an SST and their preference was for a 70-passenger Mach 2-2.2 medium range aircraft. (Sud Aviation, the eventual partner for BAC, was based at Toulouse and in 1970 became part of Aérospatiale [originally Société Nationale Industrielle Aérospatiale or SNIAS] through a merger with Nord Aviation and another company, SEREB.)

The UK delegates added that it appeared from investigations that the higher speeds were less attractive over European stages of 500-600 miles (805-965km), and it appeared that speeds in excess of Mach 1.3 or 1.4 were not attractive for European routes at all. For African and Far Eastern services, operations over stage lengths of some 2,500 (4,025km) miles plus were essential, and an aircraft with this range could also be stretched to suit transatlantic flights. These were however provisional views and work was still proceeding to clarify these questions, and on the technical difficulties of producing an aircraft with good subsonic and supersonic characteristics and capable of operating from small airfields (such as would be required in Europe).

The broad outlines of some possible arrangements for collaboration were then sketched out by the UK



During the early years of the Concorde project the manufacturers produced a series of publicity artworks and display models which, although showing the same general configuration, displayed subtle detail differences as the design matured. This is an early original artwork.

delegation, assuming that agreement could be reached on the development of a common aircraft. If this was achieved then an agreed specification would be formulated and the design team would break down the aircraft and allocate the design and production of component parts between the industries of both countries. However, responsibility for the development of the engine could not be split, and it might be more appropriate for this to be a UK responsibility and financed by the UK.

With regard to finance, general UK policy was that Government support did not necessarily imply that all the development expenditure would be provided from Government sources. It was also the UK's opinion that it would be easier to decide to embark upon the project if it were clear that the national airlines would buy the finished product.

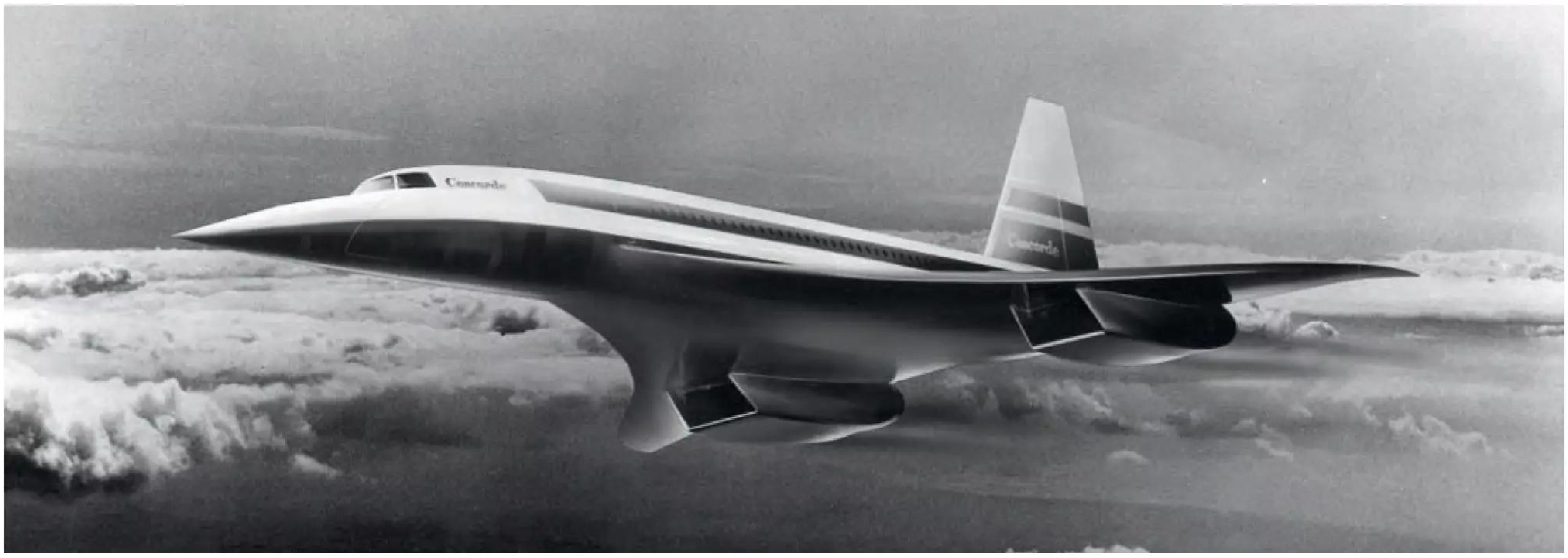
The French delegation was generally in agreement with the proposals for technical collaboration and thought that, if a decision was taken in favour of collaboration, French firms could join the British immediately for feasibility studies. However, with regard to their national airlines it was not the policy that the choice of the aircraft they bought should be prescribed by the Government, and indeed in the early stages it was very doubtful if any operator would willingly commit itself to a supersonic project.

Further official meetings were held in Paris in February 1960 and the French Government received, in confidence, a copy of the STAC's report. In April 1960 the question of collaboration was discussed further by Minister of Aviation Duncan Sandys and Robert Buron, the French Minister of Transport. During these talks Sandys pressed for an early French decision on collaboration, but Buron replied saying that France could not make any decision until its own feasibility studies had been completed, which were not expected until about the end of 1960.

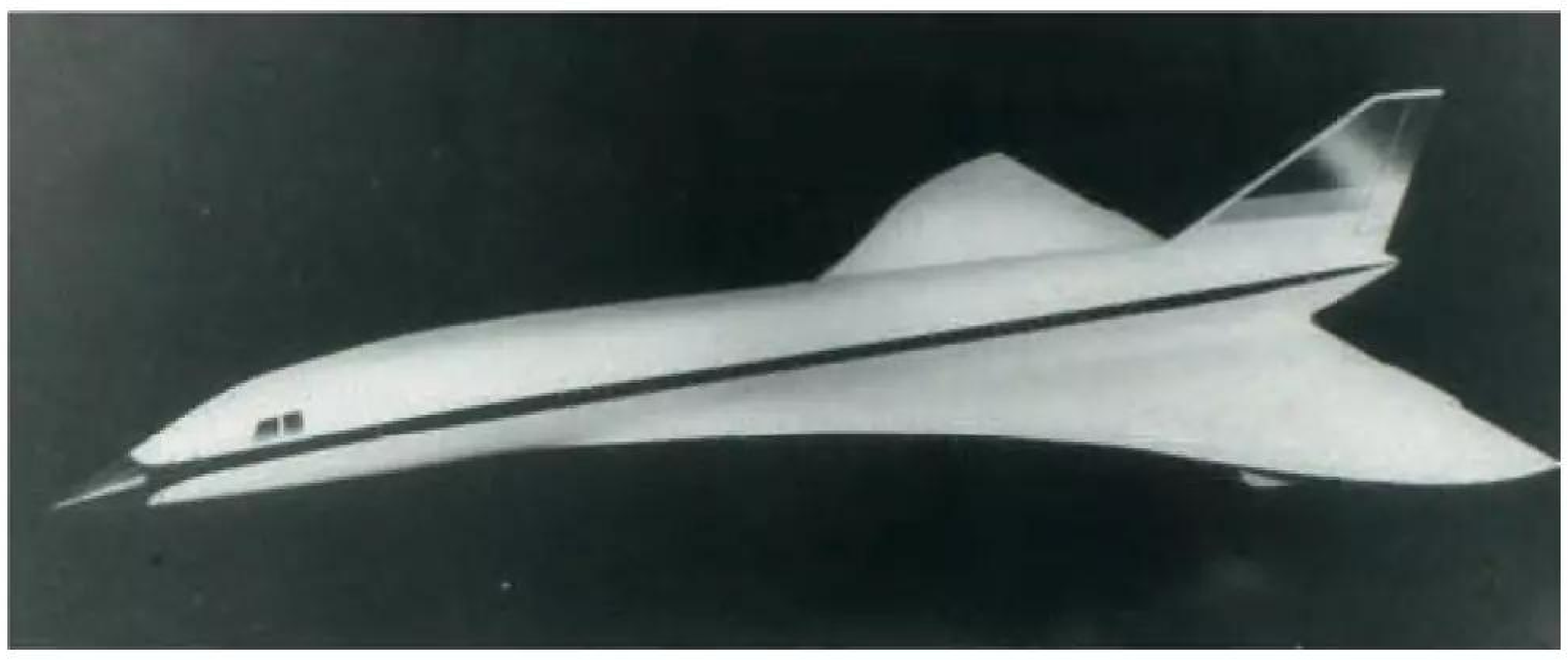
In the meantime, BAC reported that its own discussions with Sud had established that the French firm was most willing to co-operate with the British company (or whichever UK airframe group was selected), at least in the execution of a common research and development programme. Meanwhile Hawker Siddeley had had discussions with three French firms and concluded that collaboration with Dassault would be feasible, although limited to a joint study in designing and developing a long range aircraft.

On 12 April 1960 Duncan Sandys told M. Jean Blancard, who between 1959 and 1961 was the French Minister of State for the Air Force, that in the UK the position broadly speaking was now as follows:

"We have not yet definitely decided to build a supersonic transport aircraft. We think there is a strong probability that anyone undertaking the construction of the first supersonic transport would lose a lot of money over it. On the other hand, we think that a country which does not undertake research in this field is condemning itself to disappearing sooner or later from aeronautical activity. It follows that the solution consists in trying to share expenses with other countries."



This artwork shows particularly well the engine nacelles with their variable-ramp intakes. *Bristol Siddeley*



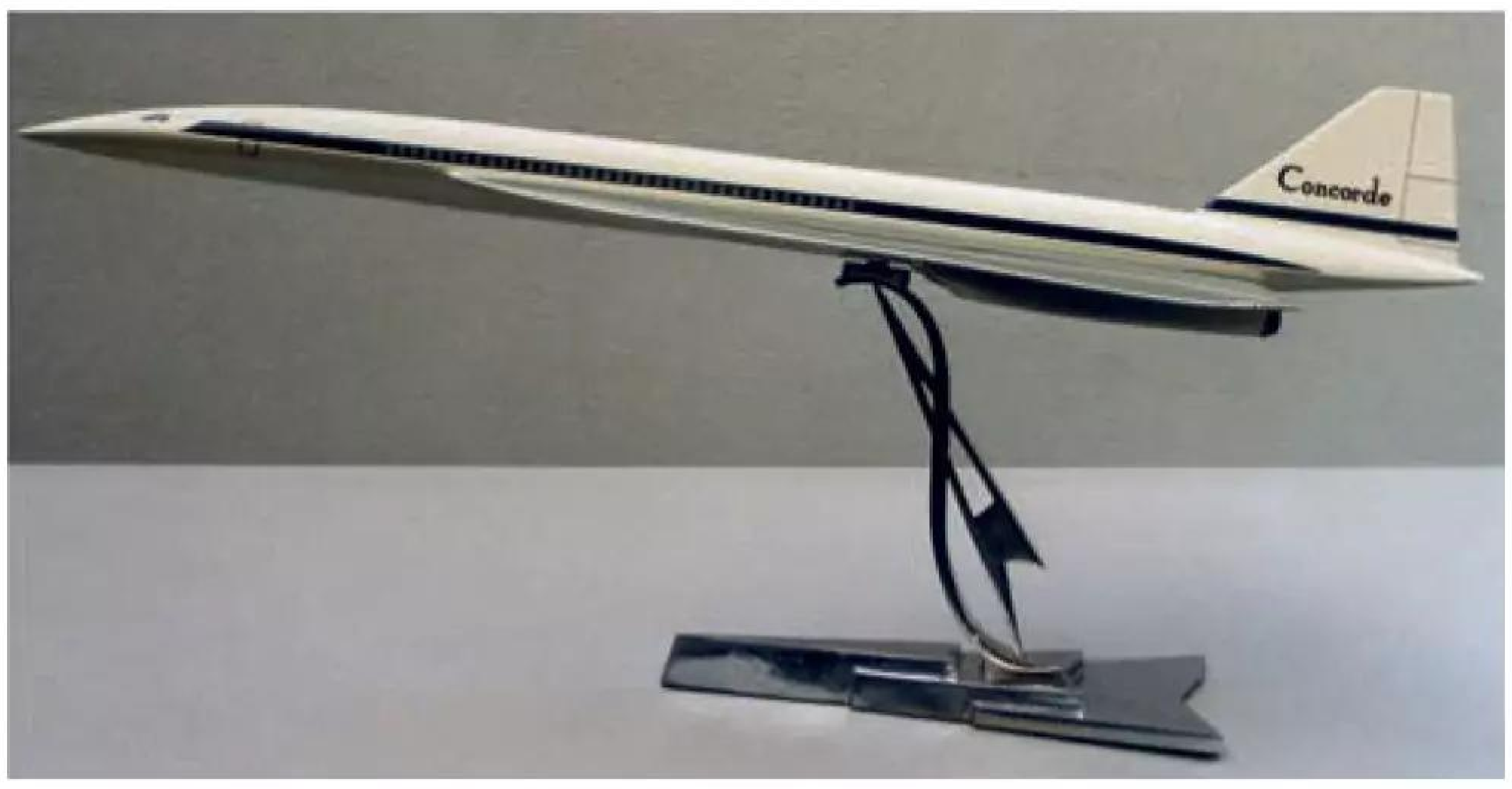
This is thought to be a very early Concorde project model.

Peter Thorneycroft then replaced Sandys as Minister of Aviation in July 1960.

On 27 October 1960 it was announced to the House of Commons that the British Aircraft Corporation had been selected to undertake the work on the supersonic transport airframe. However, it was made clear that no decision on a supersonic project was likely without convincing proof that collaboration with America and/or France had been thoroughly explored. Dr Cawood said the French had given very little away regarding their plans but it was clear that their inclinations were towards a short range Mach 2 aircraft, since they felt that a long range type was beyond their resources. The next step was an exchange of views between the nations' Ministers, an important step because the organisation of the French aircraft industry favoured a Government to Government approach.

BAC AND SUD

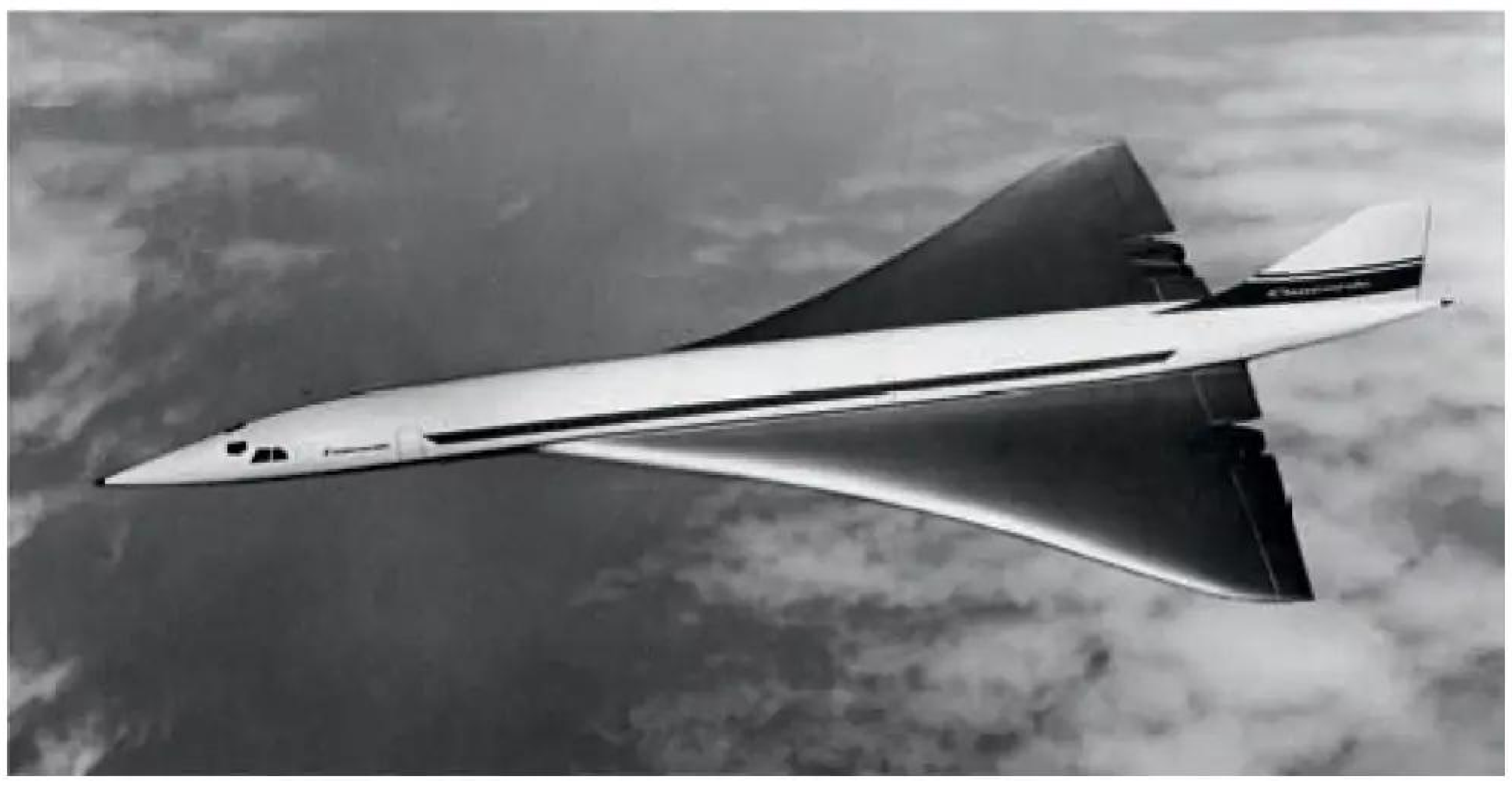
BAC Bristol's Dr Russell then told the Ministry on 18 January 1961 that his firm had received proposals for collaboration from Sud Aviation to cover common research and development problems such as those associated with materials. If the French then went ahead with the development of a medium range aircraft, the intention would be to install the same equipment and engines as would be used in a British long range version. The French, however, were not proposing to contribute to the development of the engine.



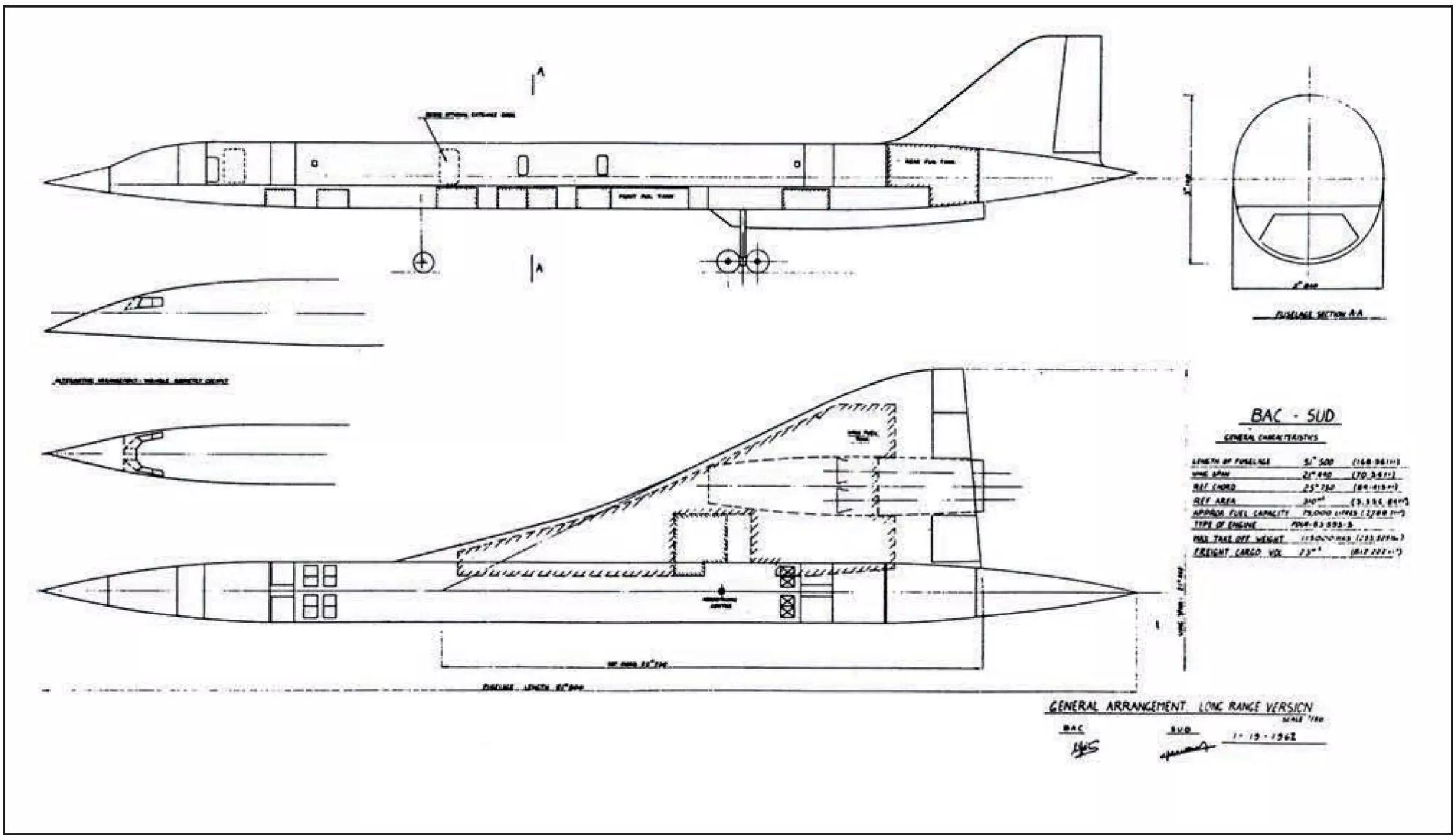
Another early model view.

BAC was asked to explore further the possibilities of collaboration with France and a resulting report declared that the French attitude was dominated by their success with the Caravelle. This had led them to the conclusion that it was best to avoid direct competition with major American manufacturers, and implied interest only in a relatively small aircraft which by implication would have less than transatlantic range.

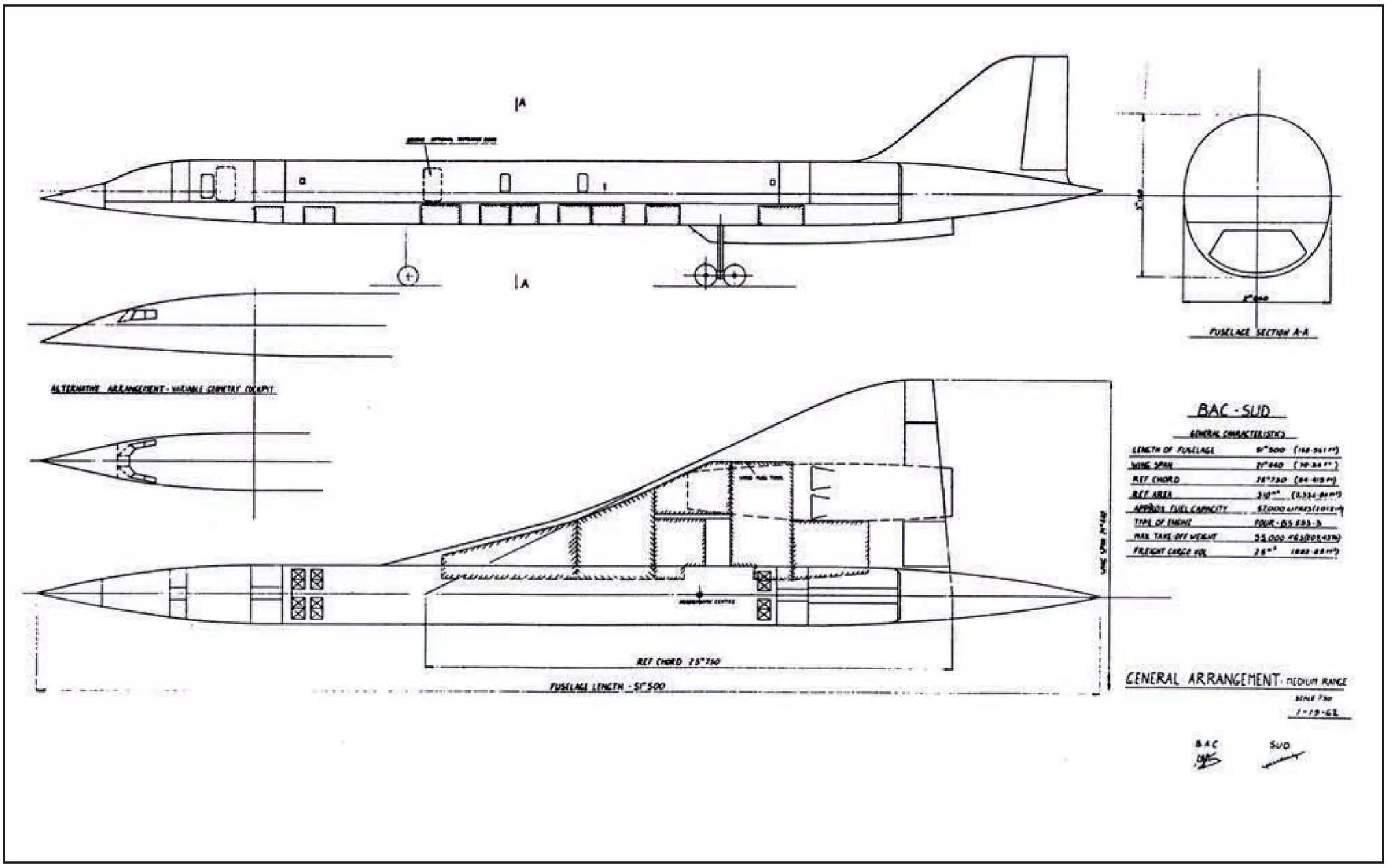
Design studies had been placed with Sud, Nord and Dassault, based on a specification calling for about 80 passengers and a range now of only about 1,800nm (3,335km). These studies were due to be submitted at the end of July 1961. The Sud design had also adopted



A model and a background cloudscape are combined to produce an attractive Concorde 'in flight' view for publicity purposes.


BAC - SUD
GENERAL CHARACTERISTICS
LENGTH OF FUSELAGE
WING SPAN
REF CHORD
REF AREA
APPROX FUEL CAPACITY
TYPE OF ENGINE
MAX TAKE OFF WEIGHT
FREIGHT CARGO VOL
FUSELAGE SECTION A-A
A
A
GENERAL ARRANGEMENT LONG RANGE VERSION
BAC
SUD
1-19-1962

Official drawing dated 19 January 1962 showing the long range version of the proposed BAC/Sud SST. *BAE SYSTEMS*


BAC - SUD
GENERAL CHARACTERISTICS
LENGTH OF FUSELAGE
WING SPAN
REF CHORD
REF AREA
APPROX FUEL CAPACITY
TYPE OF ENGINE
MAX TAKE OFF WEIGHT
FREIGHT CARGO VOL
FUSELAGE SECTION A-A
A
A
ALTERNATIVE ARRANGEMENT - VARIABLE GEOMETRY COCKPIT
REF CHORD 25m750
FUSELAGE LENGTH - 51m500
GENERAL ARRANGEMENT - MEDIUM RANGE
SCALE 1/50
1-19-62
BAC
SUD

The equivalent drawing for the medium range version shows exactly the same airframe but with re-arranged fuel tanks in the wings. The design's length was 51.50m (168ft 11.5in), span 21.44m (70ft 4in) and wing area 310m2 (3,333ft2). The long range fuel capacity was given as 79,000lit (17,374gal) for a maximum take-off weight of 115,000kg (253,527lb), with the equivalent figures for medium range 57,000lit (12,536lit) and 95,000kg (209,436lb) respectively. *BAE SYSTEMS* a slender delta form very similar in shape to that being developed by BAC, and the disposition of its engines was also in a similar position on the wing; the Sud project's design speed was Mach 2.2.

The earliest proposals for collaboration were warmly received and it was agreed that both an interchange and sharing of development would be of mutual advantage. One very important aspect was that both the medium and longer range versions of the aircraft should use the same engine and that its installation should include the intakes and nozzles, making it as alike as possible within the limitations of variation of local wing geometries.

Very recently the two firms had informed the Ministry of Aviation jointly that the engine most suited for both projects was the Olympus 593 and a request had been made for development support. Subsequently BAC agreed with Sud Aviation to explore jointly the possibility of a larger aircraft than the one they were currently working on. This would carry around 100 passengers over a range of 2,600nm (4,820km) and its performance represented the approximate limit consistent with the thrust available from four Olympus 593 units.

The meetings and discussions continued and at St Giles Court on 29 June 1961 BAC's Sir George Edwards provided an account of the latest round of talks between his company and Sud Aviation. Dr Russell and Sud's Pierre Satre had now virtually agreed on the feasibility of developing a supersonic transport as a joint project and with the following specification: range 2,500nm (4,635km); powerplant four Olympus BS.593/3 26,000lb (115.6kN) static thrust engines; gross weight 200,000-230,000lb (90,720-104,330kg), seating capacity around 100. It would also use the current slender delta configuration.

Further inter-company discussions were planned and some firm proposals, together with an assessment of the market prospects, should be ready for submission by the end of July. Edwards added that both design teams favoured a straight jet engine and BAC's reasoning for its preference for the Bristol type was that this development of the Olympus for the RAF's TSR.2 supersonic bomber would be of great value in producing the SST power unit; conversely the work on the latter engine would tend to reinforce the military project. There was also more ground for confidence in the Olympus 593 estimates than for those for a completely new engine.

INTERESTING THE AIRLINES

Sud Aviation had agreed to seek the views of the airlines Air France and UAT (Union Aéromaritime de Transport), the latter of which had so far shown the greater interest in the supersonic project. BAC proposed to consult BOAC, but the British firm had disagreed with Sud over the weight schedules of the original French [Super Caravelle] design, which were far too optimistic as in the case of the original Caravelle.

In addition, Edwards was doubtful whether the present rate of spend should be allowed to rise very much over the next 6-12 months because this would allow time for a really thorough technical appraisal of the new design, it would allow time for a valid appreciation of market prospects (which could only be done through detailed discussion with the prospective operators) and, although BAC was optimistic of the prospects of a commercial deal with Sud, the negotiations between the British and French Governments would inevitably be prolonged.

One danger in the recommended course of action was if the Americans decided to go for a Mach 2 long range aircraft after all rather than Mach 3. Should this happen then the UK and France would lose a valuable time advantage, but on present showing the Americans were still firmly adhering to Mach 3. In addition, Sud did not wish to collaborate on a non-stop transatlantic aircraft since they had originally decided on a medium range SST with the intention of forestalling others in the supersonic field. Finally, Edwards stressed that the French estimates and ideas about the timescale for producing the SST were totally unrealistic, having spoken in terms of a first flight by April 1965.

In January 1962, BAC and Sud proposed a joint slender wing light alloy Mach 2.2 aircraft project. This formula was still considered to be the correct one for the first generation of SSTs and its powerplant was to be four 26,000lb (115.6kN) Bristol Siddeley Olympus 593/3s. After frank technical discussions the two firms had agreed to present a configuration based largely on the Sud Aviation Super Caravelle project which had been developed continuously over a period of two and a half years.

Now the two firms considered that the two versions of the aircraft, i.e. medium range and long range, could be produced with probably not more than about 10% difference overall, and at the most only quite minimal variations in their external shape. They would in fact have basically the same passenger cabin, the increased fuel tankage in the long range version being carried in the outer wings and in fuselage tanks which did not encroach on the cabin space. The cabin was designed to take 100 passengers, though this could be increased to around 110 by reducing the seating to tourist standard, and then further to 120 for the reduced range aircraft by using up some of the rather generous baggage space provided in the longer range version.

The medium and long range versions would have respective design stage lengths of 2,450nm and 3,250nm (4,540km and 6,025km) with sufficient excess tankage to ensure that London to New York could be flown in accordance with BOAC's needs. The weight of the long range version was estimated to be 253,000lb (115,000kg), with the medium range aircraft being around 44,000lb (20,000kg) lighter. Both versions would possess a shorter take-off run than the subsonic Boeing 707 while their landing distance would be comparable to that aircraft.

Next, following a meeting in London on 26 March 1962 between Buron and Thorneycroft, draft proposals for a Franco/British Agreement for collaboration on the development of a Civil Supersonic Transport Aircraft were submitted to their respective Governments. These outlined the following points:

1.1 The BAC-Sud Aviation outline scheme of 19 January 1962 (i.e. the design described above) would serve as the basis for joint implementation.

1.2 The basis of the collaboration would be the division of responsibility on the one hand for development and on the other for production (including spares) at a level very close to 50/50 for the overall project (airframe, engines, systems and equipment) and measured in terms of the expenditure incurred in each country.

1.3 To implement the programme an integrated organisation of the two national industries would be set up as proposed by the companies and approved by the two Ministers.

1.4 A Standing Committee of officials from the two countries would supervise the working of this programme, it would report to the Governments and would propose appropriate measures.

A COMMON AEROPLANE

The outcome was a common basic aeroplane to be produced in two versions, one complying with the medium range requirements specified by the French Government and approved by Sud, with the other meeting British Ministry of Aviation long range requirements and approved by BAC for London to New York services.

The great majority of the development and approval tests would be common to the two types and the airframe would include a high proportion of common parts and structure with the majority of assembly jigs and production tooling the same. The refined maximum take-off weights for medium and long range were now given as 209,400lb (95,000kg) and 253,500lb (115,000kg) and their fuel capacities were 12,536gal (57,000lit) and 17,374gal (79,000lit) respectively. Both designs were also shown with a variable-geometry 'droop' nose arrangement as an alternative to the conventional fixed nose, but this item would need further consideration and assessment.

At a meeting at St Giles Court on 20 September 1962 Colonel Delacroix, the Assistant to the Directeur de Transport Aérien (Director of Air Transport), said that the French Government was still assessing the results of the feasibility studies compiled by its three manufacturers. Though no decision had yet been made as to whether to embark on the project, it had been concluded that a medium range SST was definitely feasible and it offered operating costs not very different from those of subsonic jets.

If France decided to proceed with its airframe project, the intention was to build two prototypes and to perform a flight trials programme before embarking on any production aircraft. It was expected that the first aircraft would be built four years before entering service and three years before production. BAC's plan was to use the first five production aircraft for development flying and the comparable timescales were: France – prototype flying 1964, second prototype flying 1966, production 1968, service 1969; Britain – first flight 1966, service 1969.

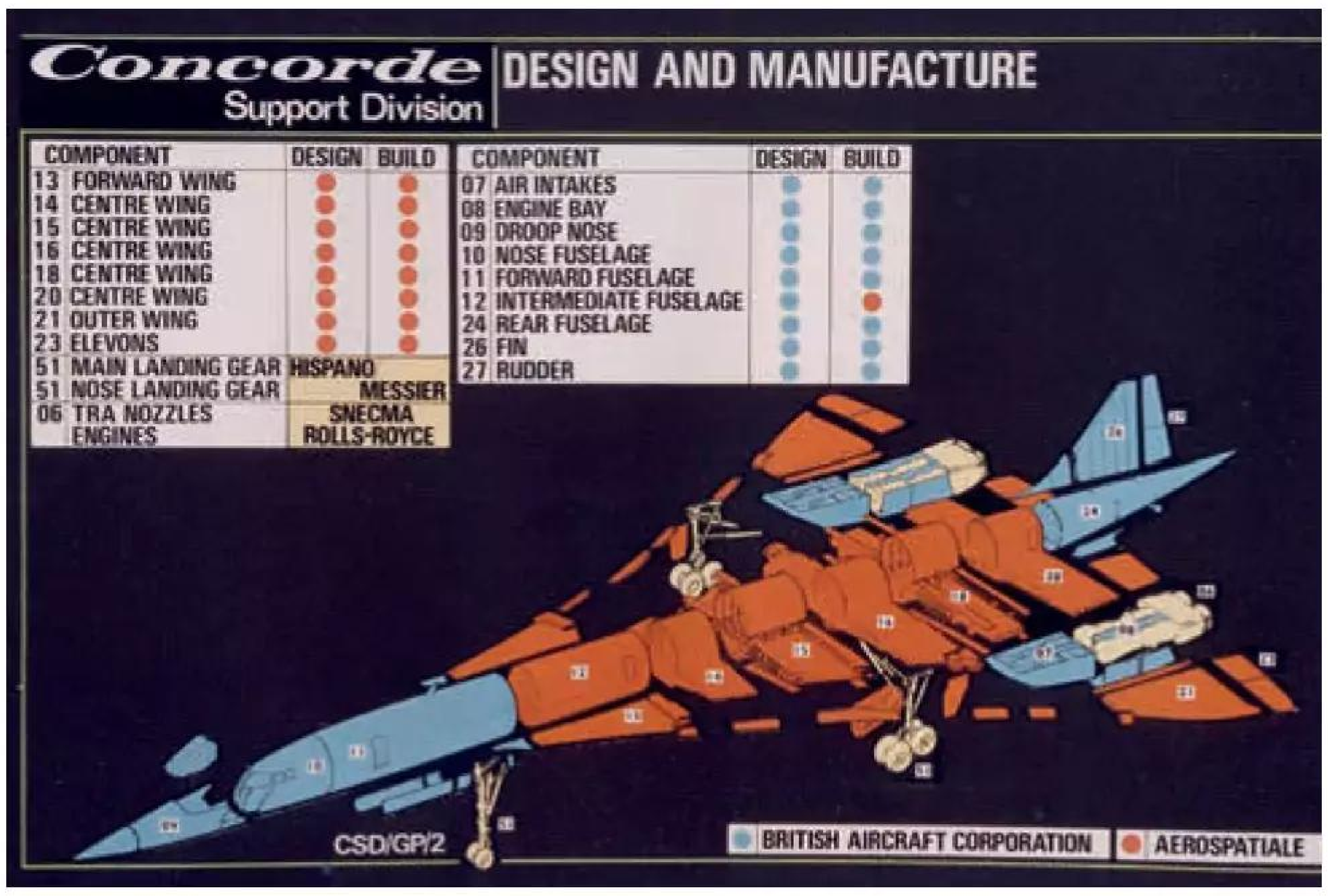
On 27 September 1962 the new Minister of Aviation Julian Amery (who had replaced Thorneycroft the previous July) explained that the French had decided to develop a Mach 2 airliner whether the UK joined them or not. The project was too big and too risky for the UK to undertake alone and it was now a question of whether to join the French or not.

AGREEMENT AT LAST

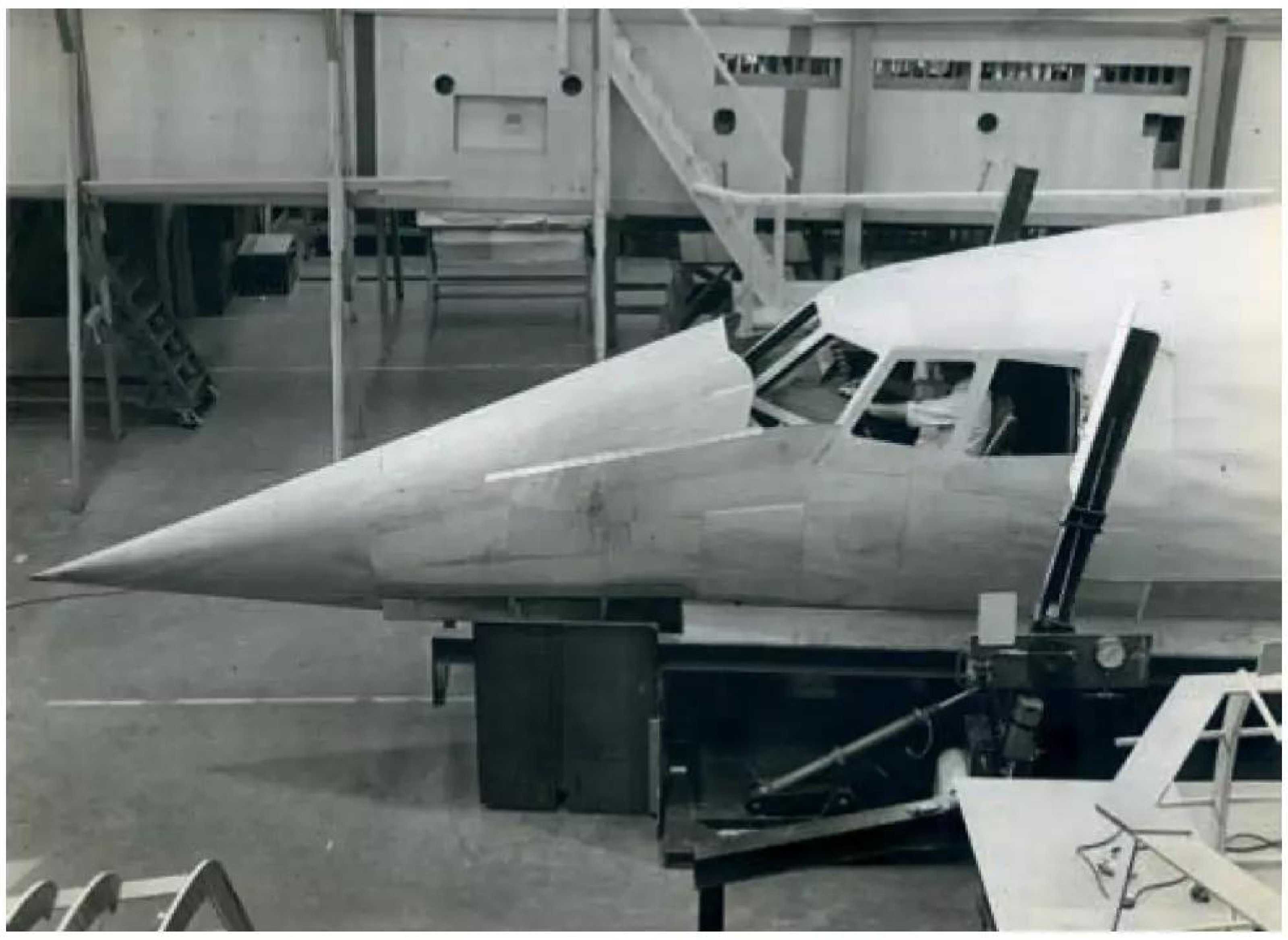
By October the two companies had produced fuller technical proposals for their SST. Then finally, on 29 November 1962, an agreement between the governments of France and Britain was signed at Lancaster House in London and registered at the Hague. The signatories were Amery and France's Ambassador to the UK Geoffroy de Courcel. That same day Amery addressed the House of Commons to announce that a final agreement had been reached to go ahead with the Anglo-French project for a supersonic airliner, and it was to be called the Concord.

The aircraft would cruise at about Mach 2.2 and would cut the present Atlantic crossing from 7.5 hours to around 3 hours. A first flight was expected in 1966 with airline service by 1970. Amery also reported that "the British share of the costs of development, and of jigging and tooling for production, is estimated at between £75m and £85m. This will be spread over the next eight years or so. It will mainly be met by Her Majesty's Government, but the firms will make an appropriate contribution. BOAC and Air France will be associated with the project from the beginning."

Geoffroy de Courcel, France's Ambassador to London (left), and Julian Amery, Britain's Minister of Aviation, examine a Concorde model during the joint agreement signing ceremony held at Lancaster House on 29 November 1962. *BAE SYSTEMS*


Concorde
Support Division
DESIGN AND MANUFACTURE
COMPONENT
DESIGN
BUILD
13 FORWARD WING
14 CENTRE WING
15 CENTRE WING
16 CENTRE WING
18 CENTRE WING
20 CENTRE WING
21 OUTER WING
23 ELEVONS
51 MAIN LANDING GEAR
HISPANO
51 NOSE LANDING GEAR
MESSIER
06 TRA NOZZLES
SNECMA
ENGINES
ROLLS-ROYCE
COMPONENT
DESIGN
BUILD
07 AIR INTAKES
08 ENGINE BAY
09 DROOP NOSE
10 NOSE FUSELAGE
11 FORWARD FUSELAGE
12 INTERMEDIATE FUSELAGE
24 REAR FUSELAGE
26 FIN
27 RUDDER
CSD/GP/2
BRITISH AIRCRAFT CORPORATION
AEROSPATIALE

Schematic drawing showing a breakdown of the work share between Britain and France on Concorde. *BAE SYSTEMS Heritage, Farnborough*



Early full-size mock-up of the Concorde droop nose.

Each country would assemble one prototype and one pre-production aircraft and each company would be responsible for the flight and acceptance testing of the aircraft it completed. For both prototypes and production aeroplanes each country would in general produce the assemblies, sub-assemblies and individual components it had designed and then these would be fitted together on two final assembly lines, one in each country. This removed any duplication of the primary production jigging and the appropriate components produced for the other country would be transported to the second assembly line.

BAC would be responsible for the forward fuselage (including the droop nose), the rear fuselage, the fin and rudder, and the engine nacelles. Sud would look after the centre of the aircraft, the front portion of the wing, the elevons and the undercarriage. Britain would also be responsible for the engine controls, fuel system, electrical generation, the oxygen system for crew and passengers and the distribution of air within the cabin, and thermal and sound insulation.

France would design the hydraulics, flying controls, radio, navigation systems and air-conditioning. With the exception of the aerodynamic design and testing of the engine nacelles, intakes and nozzles, the French would also deal with all of the aerodynamic side. Sud would undertake 60% of the airframe work with BAC doing the rest, the engine development split balancing the total out to 50/50. A joint organisation would oversee airline sales and it was accepted that Britain and France would get equal sharing of any and all sales proceeds, but acquisitions by any military air arms would be subject to separate agreements.

Bristol Siddeley Engines would design, develop and build the basic Olympus 593 (compressor, combustion chambers, turbine) while the French SNECMA company (Société nationale d'études et de construction de moteurs d'aviation) would design and build the rear end – the reheat unit, nozzle and jet pipe including noise suppressor and thrust reverser.

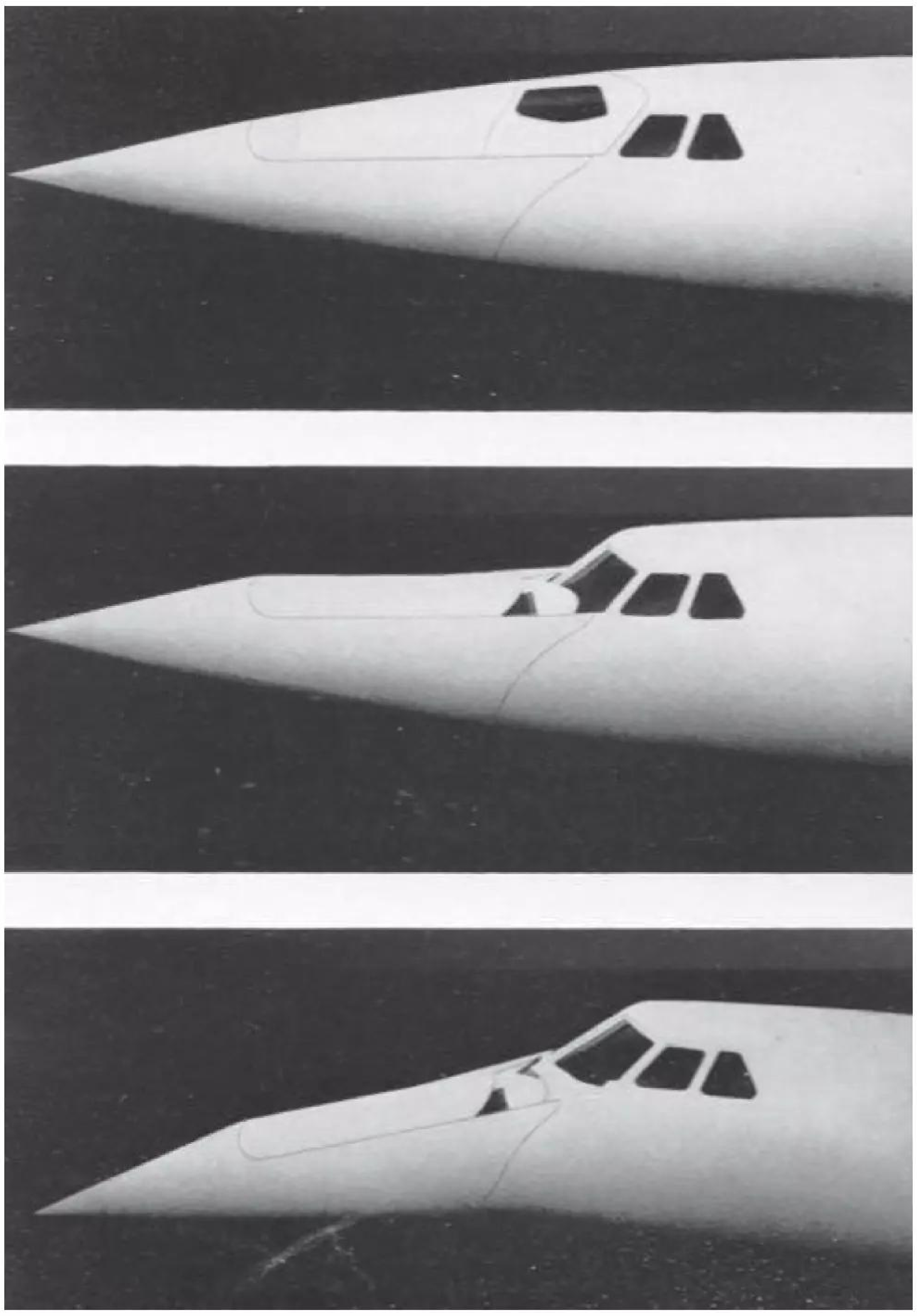
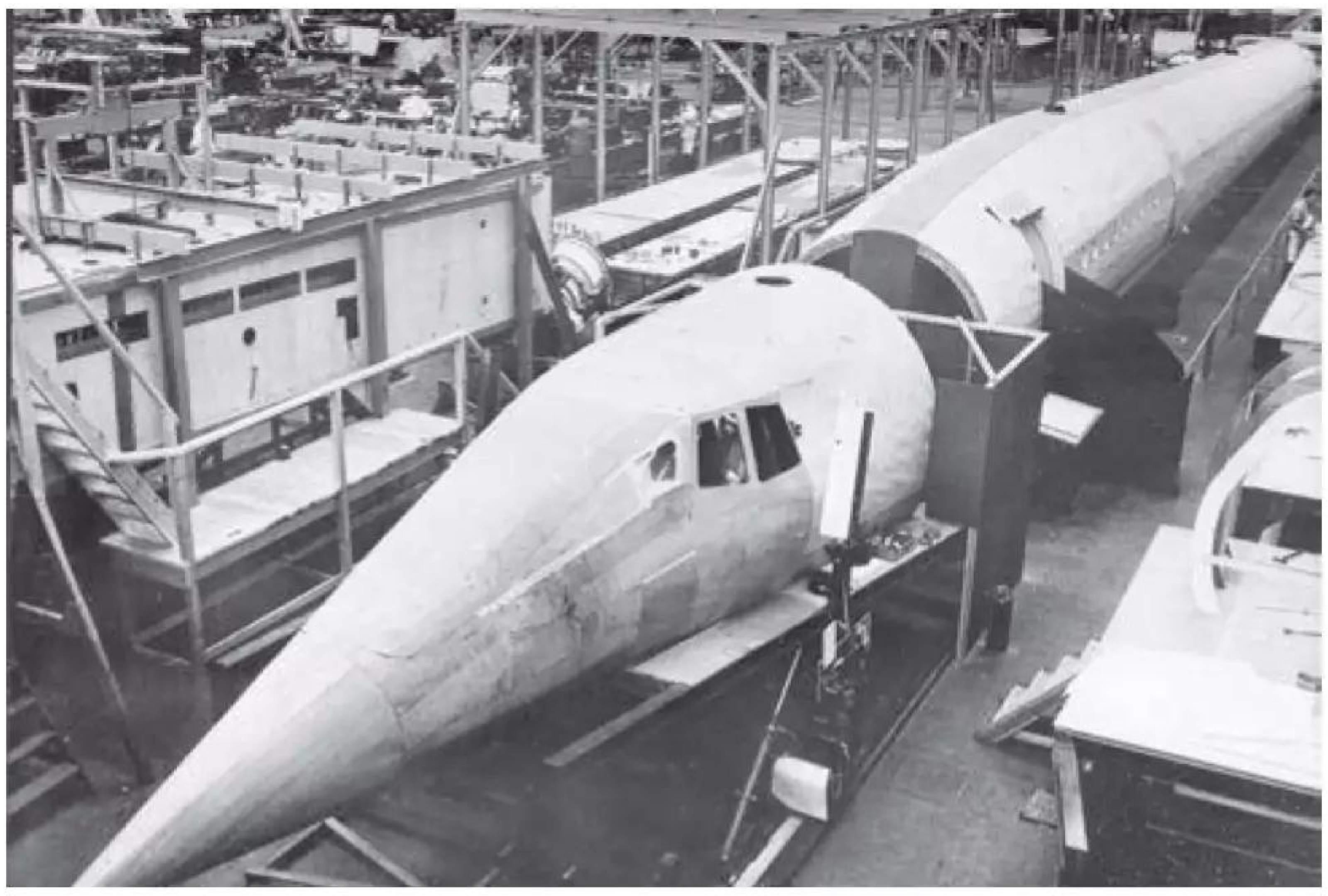


Photo sequence of the nose mock-up showing the different stages between fully up for supersonic flight and full drooped for take-off and landing. *Sud Aviation document via JC Carbonel*

The engine companies would build examples of the Olympus 301 and 22R for some early full scale ground trials, and then follow these with Olympus 593s made specifically for bench trials, steps which were intended especially to help develop the reheat system and variable convergent-divergent nozzle. The engine development work was to be



The complete Concorde fuselage mock-up. *JC Carbonel*

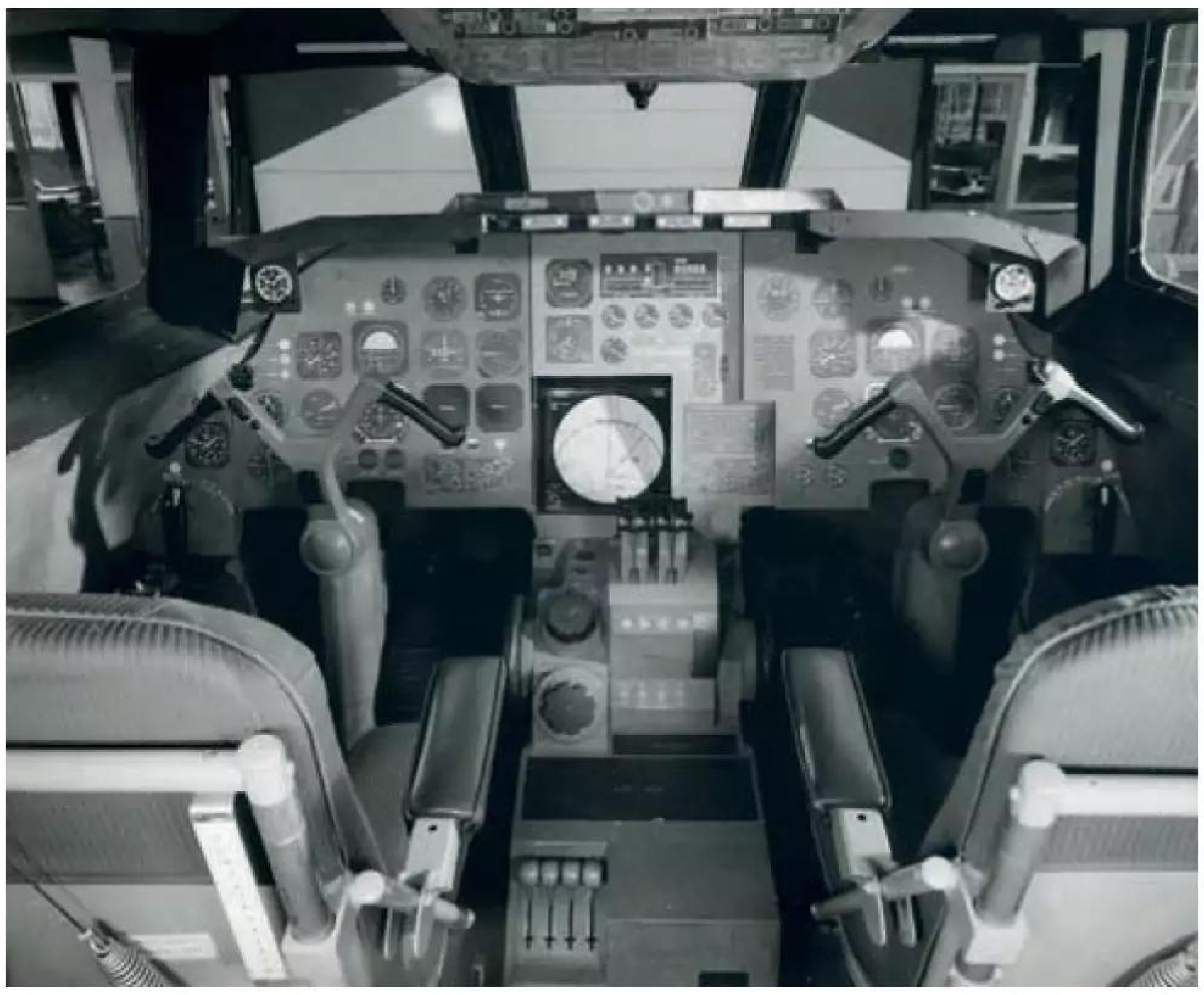
View showing the Concorde mock-up exterior. *JC Carbonel*

split to about two-thirds Bristol and one-third SNECMA, and then for production 60% Bristol and 40% SNECMA. This official statement committed BAC and Bristol Siddeley Engines to the biggest single technical task the two firms had ever undertaken.

CONCORDE TIMETABLE

With a formal go-ahead given in December 1962, and with a first production order placed before 31 March 1965, the provisional Concorde timetable was given as: first flight of the first prototype during the second half of 1966; first flight of the first production aeroplane at the end of 1968; Certificate of Airworthiness at the end of 1969.

Full-size mock-up of the Concorde passenger cabin.



Cockpit mock-up at Filton.

This agreement to build Concorde was now unstoppable, since it did not contain any clause to permit a possible breakaway by either party. The name Concord, or Concorde in France, was officially confirmed shortly after the agreement had been signed, but it was not until 1967 that Concorde with an ‘e’ was officially adopted by the British.

A separate set of UK discussions, underway at the same time, had considered whether the airlines as potential customers would need or necessarily wish to operate a supersonic transport aircraft. These talks were aimed primarily at BOAC, but for a period the RAF was also consulted. The airlines which first successfully operated the aircraft would clearly obtain some initial gain in revenue, but they would also have to bear the burden of any teething troubles. On balance, it was questionable whether there would be a significant long term advantage, but from the point of view of the manufacturer the advantages of being first in the field with a successful new type could be very great indeed.

A nice model of an early Concorde on display at an Austrian Air Show in 1963. (Please Note: this is an aviation book – you are only supposed to look at the aircraft!). *Philippe Ricco*

BOAC CONCERNS

On 3 August 1961 Sir Matthew Slattery, chairman of BOAC, gave a press conference which considered the benefits given by the supersonic transport. At the time BOAC was in some debt, much of it incurred from having to 'buy and troubleshoot' new British aircraft, and as a result relations between airline and government were not comfortable.

In what was really a statement, he said he thought that supersonic flight would not benefit the tourist and that the businessman would not welcome the loss of his present respite of five to six hours over the Atlantic. It would be of benefit in an emergency when people and supplies could be carried as quickly as possible to save life. Even so Slattery went on to declare "having said all that, I am perfectly convinced that there are going to be supersonic transports provided we can overcome the noise problem, and more or less regardless of the economic cost". Because of this he was determined that BOAC should neither be left behind in the race nor be found unready to meet the challenge.

However, if the operating costs of a supersonic transport across the Atlantic were going to be 10 to 50% higher than those of present aircraft types, then the market would be small and British companies would be lucky if they sold 25 aeroplanes. Amortisation of development costs might then necessitate a surcharge on fares that would reduce the attraction of the aircraft to the airlines. But if amortisation could be spread more widely then the market might grow to a total of 100 or even 200 aircraft.

Thus the venture had become a gamble on the number of aircraft sold. On top of this, if the noise created by the supersonic type was above that of present day aircraft it would be intolerable, but noise suppression would be expensive, thus adding to the cost of the aircraft. The supersonic bang might even mean it would not be possible to operate this aircraft over populated land masses.

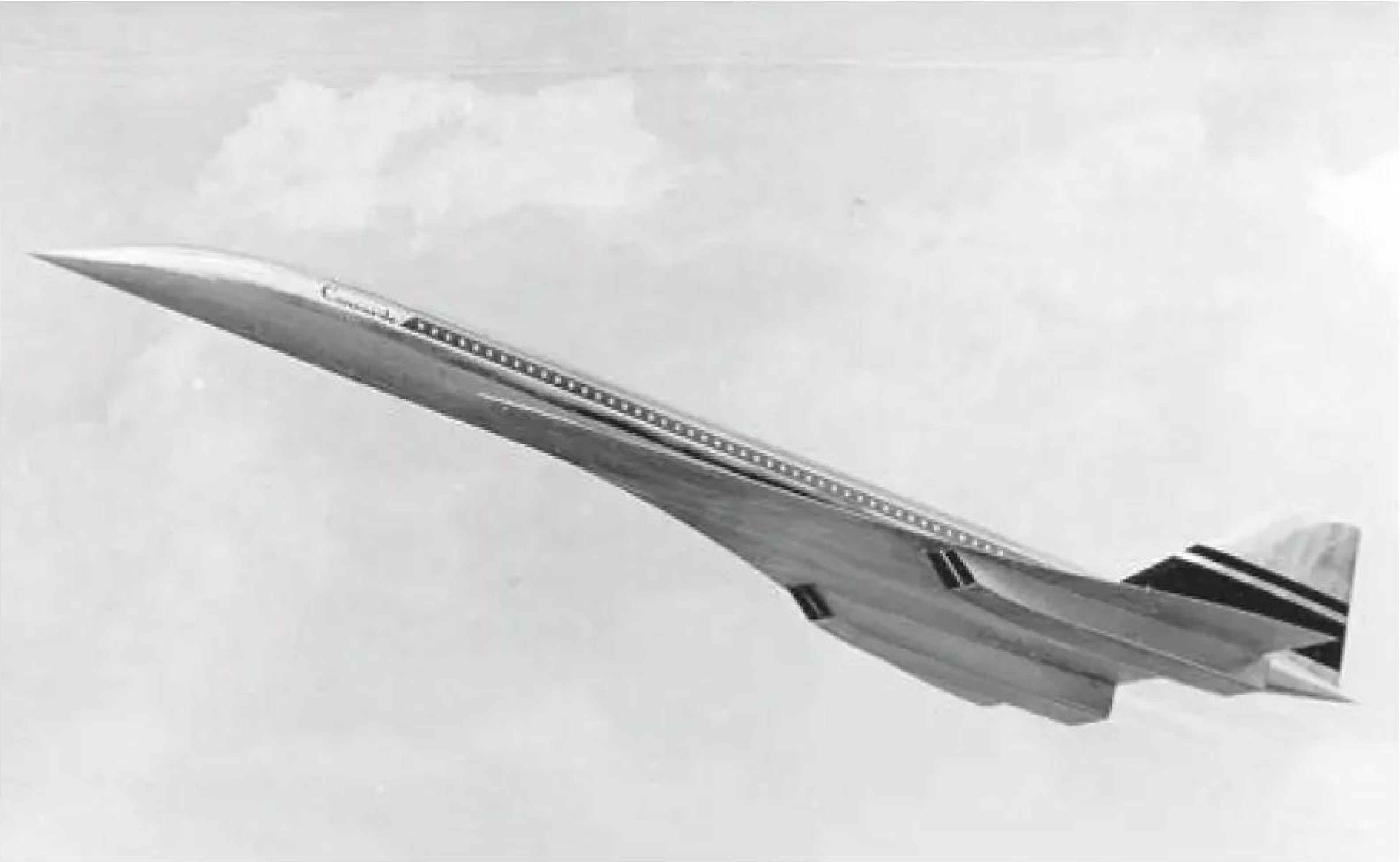
A BOAC statement on 29 November 1962, on the same day as the agreement between France and Britain had been signed, reported how the airline had kept in touch with the preparatory work, and believed that a promising foundation had been laid in the form of the Anglo-French project. In addition BOAC would cooperate with both the British and French manufacturing companies so that its experience as an operator could be used in the further evolution of the design. To back this up, during December 1962 Slattery set up within BOAC a Supersonic Transport Aircraft Working Party.

OTHER NATIONS

During mid-1965 discussions did take place with Italy and West Germany. Talks with the Italians were held in Rome on 28 May 1965 and all indications suggested that they were willing to participate in the Concorde programme but they questioned the financing of the project. They also wanted to know what part of the work could be given to the Italian aircraft industry and were worried by the American SST programme. In the end, the Italian government decided not to participate.

A second meeting followed on 1 June 1965 with the West Germans in Bonn. However, it was reported that "Germany is not particularly eager to get into this particular sector of the advanced technology and to assume the associated risks". Instead it was suggested that the required effort and funds would be better used to improve the communications between city terminals and airfields. The sonic boom situation was also questioned by the Germans, as was the competition with the US Mach 3 SST programme where it was pointed out that the American aircraft had won more orders from airlines than had Concorde.

Finally, the Germans wanted to know what the Italians had said the previous week. A rather optimistic postscript to the summary report added that the Germans might consider participating in the Concorde programme if they were offered 'satisfactory participation' in another project, like a 'heavy-lift aircraft'. ◆



An early model of Concorde with what appears to be Stage 2 in the process of nose development. *Sud Aviation document via JC Carbonel*

6

Research and Development

F-WTSA
AEROSPATIALE FRANCE – BRITISH AIRCRAFT CORPORATION

The cutting edge of civil aircraft technology in the 1960s and 1970s. This view shows the second pre-production Concorde F-WTSA, which was the fourth aircraft to be manufactured.

Flying at Mach 2, though less problematic than flying at Mach 3, still presented significant challenges. The temperatures Concorde would encounter at such speeds could alter the properties of the materials used in its construction and additional stresses would result from the non-uniform distribution of heat throughout its airframe.

Some time before the British and French Governments began their separate SST feasibility studies, with aluminium alloy as their main structural material, the research and development division of High Duty Alloys Limited (HDA – part of the Hawker Siddeley Group) had begun to compare the relative merits of alloys in the Hiduminium range in anticipation of this possible new application.

Hiduminium RR.58 is a complex aluminium-copper-magnesium-nickel-iron alloy and was first produced by HAD during the Second World War specifically to manufacture forged components for the new gas turbine aero engine; for example the forged impellers in the Whittle units used by the Gloster Meteor Mk.I jet fighter.

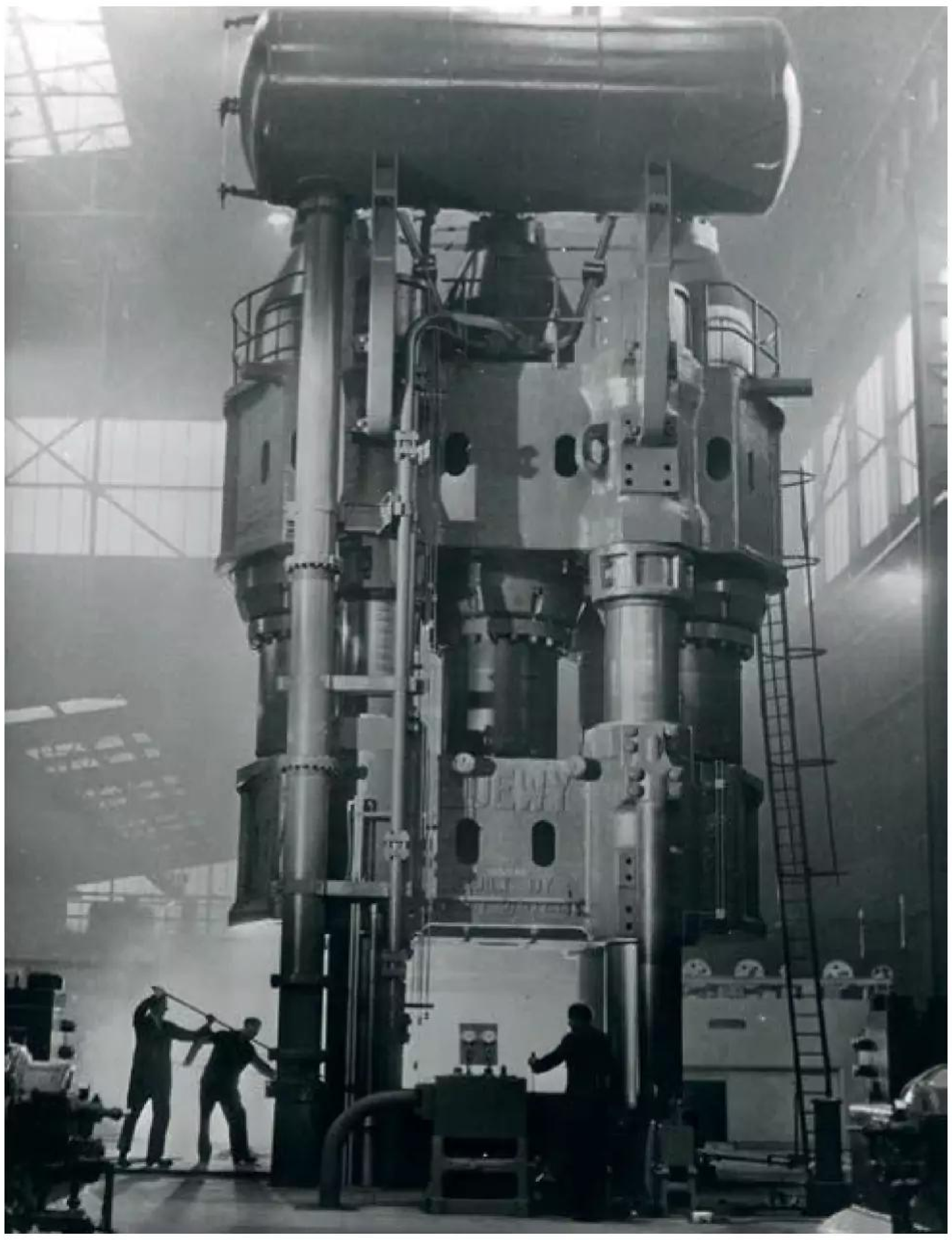
It was appreciated that the airframe life requirement would be 20,000-30,000 flying hours (in fact the Concorde airframe was designed for a life of 45,000 hours) and that the saturation skin temperature (through kinetic heating) at speeds of Mach 2.2 and 2.5 would reach about 120° and 150°C respectively.

Subsequently, the British Ministry of Aviation sponsored an extensive study of the elevated temperature properties of appropriate aluminium alloys and this resulted in the selection of RR.58. As noted, quite independently the French Ministère de l'Air had chosen the same material for its SST. In France RR.58 was produced under licence and sold under the designation A-U2GN.

RR.58's ability to withstand high temperatures for long periods of time made it ideal for Concorde's fuselage skin. Even a prolonged exposure at 150°C would not result in serious loss of properties, and temperatures as high as 200°C could be acceptable for short periods of time.

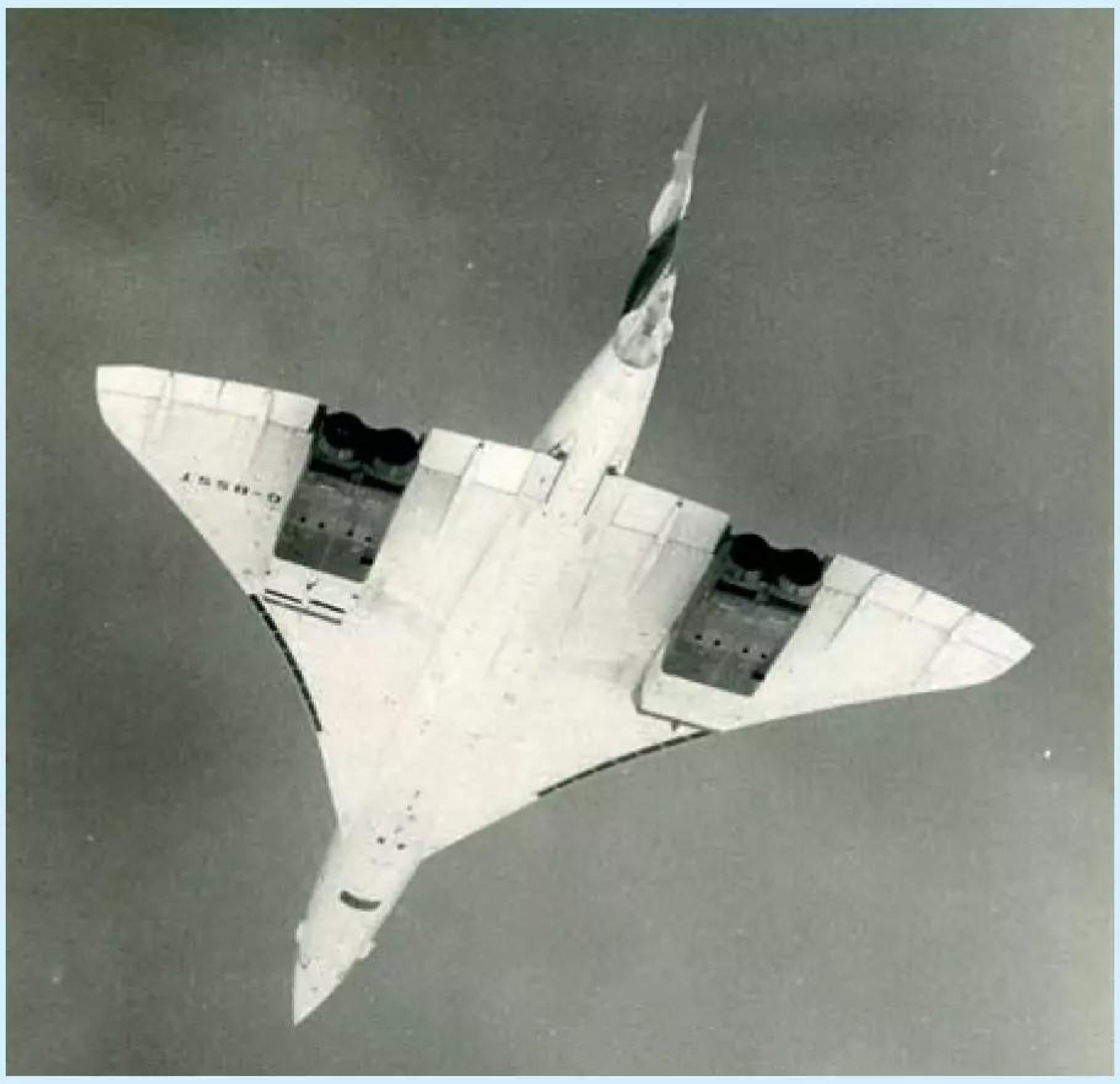
Material procurement specifications were prepared during 1963 and 1964 with Sud Aviation and BAC (along with representatives from light alloy manufacturer Cegedur in France and HDA) to cover the supply of Hiduminium RR.58 in various wrought forms.

The High Duty Alloys research division was based at Slough. This photo was taken in the 1950s. *High Duty Alloys*



High Duty Alloys' contribution to the Concorde programme came not just in the development of RR.58 alloy. The plant at its Redditch works made forgings of all sizes for both airframe and engine. This view shows the company's 12,000 ton press which produced undercarriage legs and large jet engine discs. *High Duty Alloys*

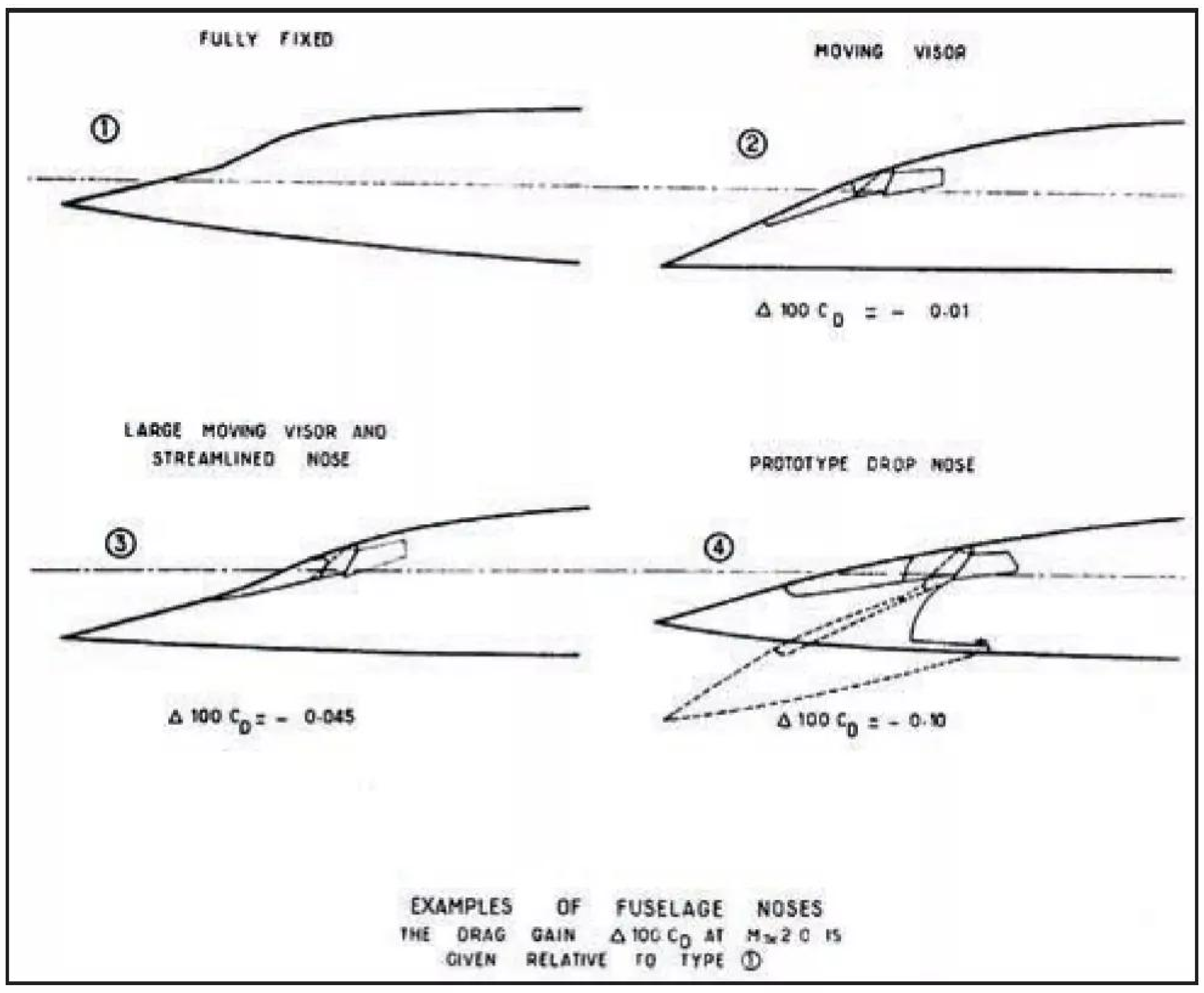
HDA's ring roller was used to make aluminium and titanium components for jet engines. *High Duty Alloys*



The airworthiness certification for Concorde's slender delta wing was based on a feature called the 'zero rate of climb.' G-BSST was the first British prototype, while G-BOAC (Concorde 204) was used by BAC to complete the airliner's Certificate of Airworthiness coverage, in particular for auto landing trails and clearing the air conditioning system. *BAE SYSTEMS Heritage, Farnborough*

During a supersonic flight Concorde would pass through two separate cycles of heating and cooling. While still flying at subsonic speed it would cool down as it gained altitude; the heating process would only start once it had gone supersonic and then build up especially as the speed approached Mach 2. The slowing down and descent towards the end of the flight meant that the reverse took place. This process, and the way it altered the airframe temperature and stresses, had to be factored fully into the metal fatigue and metallurgical modelling and testing carried out before the aircraft ever flew.

Test rigs and full-scale sections of airframe like the wing were built for ground testing on which all of the stresses and strains experienced during every supersonic high altitude flight could be applied, including heating and cooling. Periodically samples of metal would then be taken from these items for analysis to ensure that there had been no deterioration of properties.


FULLY FIXED
①
MOVING VISOR
②
Δ 100 C_D = − 0.01
LARGE MOVING VISOR AND STREAMLINED NOSE
③
Δ 100 C_D = − 0.045
PROTOTYPE DROP NOSE
④
Δ 100 C_D = − 0.10
EXAMPLES OF FUSELAGE NOSES
THE DRAG GAIN Δ 100 C_D AT M≃2.0 IS GIVEN RELATIVE TO TYPE ①

An extract from the report by Etienne Fage referred to in the text, this sketch shows the evolution of the nose. Because it is dated 1965 it still lacks the final step with the transparent visor. *Sud Aviation document via JC Carbonel*

In addition, the aircraft was designed to fly at very high altitudes (towards 60,000ft/18,290m) which would enable it to get above most of the problems created by turbulence, but the disadvantage here was that the fuselage then had to be made strong enough to withstand the higher differential pressures (outside and inside). Providing a comfortable cabin using the correct amount of pressurisation needed thicker skins, more than for subsonic airliners, and this added weight. These conflicting requirements in the design and development of an SST airframe were indeed extreme – make it too strong and it would be too heavy to enable a large enough payload to be carried.

GETTING CERTIFIED

Any new airliner has to have a Certificate of Airworthiness to permit it to transport the fare-paying public. Because Concorde was supersonic, and had a wing shape never previously used on a passenger aircraft, new rules had to be introduced because it would come under the expert scrutiny of both British and French civil aviation authorities, and by those in countries like the USA who might buy it.

On the airworthiness side, discussions were started between the British and French Authorities and the American Federal Aviation Agency. It was desirable that opinion on certain operational matters should be sounded out with the FAA and consequently in 1964, at a joint Operational and Airworthiness Group meeting, it was decided to initiate a Franco-Anglais United States Supersonic Transport group (FAUSST) to look into the operational and airworthiness areas. In due course this would grow so that other outside experts became involved.

This close-up of the nose of Concorde 001, now preserved at the Paris Musée de l'Air et de l'Espace, shows the small side strakes positioned just behind the nose which actually improved the aircraft's stability, having replaced the problematic canard surfaces. *JC Carbonel*

A new and difficult problem for the Air Registration Board was the certification of the slender delta. Previously all civil airliners had been certified based on stalling speed, but a slender delta does not stall like an ordinary wing. Another problem was what would happen if pressurisation was lost at maximum altitude. At Concorde's normal maximum flying altitude the density of the air was very low and any breach of cabin integrity would produce such a loss in pressure that the standard plastic emergency oxygen masks used by passengers on other subsonic jets would not provide sufficient help.

As a result, they would very quickly experience hypoxia – a deprivation of oxygen supply. The solution to this problem brought together several elements – a reserve air supply system was provided to augment the cabin air pressure, Concorde had smaller windows to reduce the rate of air and pressure loss if one was breached, and a rapid descent procedure was developed to get the aircraft down to a safe altitude as soon as possible. These were huge certification issues for Concorde.

Pre-production Concorde 101 G-AXDN comes into land at the Farnborough Airshow in September 1974 in a view which displays the effectiveness of the droop nose superbly. Note the overwing condensation.

DROOP NOSE (JC CARBONEL)

The Concorde droop nose and the image it presented as the airliner took off or landed might possibly be the most iconic part of the aircraft, yet this feature was not an obvious choice and went though various iterations and stages before it was eventually selected. In 1962, when the final individual Sud and BAC projects were being compared, the choice of nose for the Sud Super Caravelle design was to be an integrated movable fairing to streamline the windshield (what would become known as the 'visor').

In contrast the BAC 223 featured a drooping nose … which the French team rejected vehemently declaring "the variable geometry nose requires justification [because of] the weight penalty from its [necessary] hydraulics". But in these early stages Sud Aviation itself had not even thought about the drag that would be generated by a windshield. So instead a retractable nose fairing was introduced and various shapes of nose were tested.

Etienne Fage, senior aerodynamics engineer at Sud Aviation, stated during a 1965 conference "for the nose, compatibility between a low drag at supersonic speeds and a good visibility at low speed could only be obtained through changes in shape. In front of the pressurized cockpit the entire nose cone can be oriented downward by about 17° to enable the pilots to have normal vision [when flying] at the important pitch attitude necessary during the approach.

"Calculations showed that if a satisfactory view out during the approach was required, and without suffering a weight penalty in fuel which could add up to many tonnes, then the [need for the] drooping nose was self-evident." On the ground, the droop nose gave the crew a view stretching to about 16ft (4.9m) ahead of the aircraft's nose and when landing the pilot could see about 420ft (128m) in front of the nose wheel position.

However, the BAC 223's moving nose design on its own was not considered sufficient and the Super Caravelle external visor was also deemed as being essential as well. In essence the droop nose and visor were to be combined. But here too there would be problems because the visor, as eventually installed on prototypes 001 and 002, was an opaque two-piece light alloy metal panel which offered no direct vision ahead for the pilots. Only two small side windows had been incorporated into the design and this was viewed (or more exactly not viewed) by the pilots as being totally unacceptable.

From test pilots to certification authorities like the Federal Aviation Authority through to airline pilots invited to test the aircraft, there was a unanimous rejection of the metal visor. The test pilots who had sampled it complained said that it felt like they were inside a submarine, while John Cochrane observed that it was like "flying inside a letterbox". In the end a clear fully-glazed transparent retracting visor had to be designed (by Marshalls of Cambridge) and this involved the urgent development (by Triplex) of glass that would retain its strength at temperatures of up to 120°C. This final solution in fact made the cockpit very quiet when the aircraft was flying at twice the speed of sound, and visually it looked neater.

The discussions and trials in relation to the view out of Concorde's cockpit during supersonic cruising flight continued for a long time before the first Concorde prototype had flown and included a mock-up installation. By late March 1966 BAC had flown a BAC One-Eleven airliner with its normal windscreen blanked off to represent the Concorde supersonic 'view out' and test pilot Brian Trubshaw (reportedly) found no difficulty in flying the aircraft. But this sort of test was not thought to be sufficiently representative because it did not include the 'tunnel effect' that was expected from the solid visor's 'periscopic view' on the Concorde prototypes.

BAC also made preliminary studies looking into the possibility of fitting a full periscope and visor in front of the windscreen of another test aircraft. This would have been a very difficult and expensive step since it would almost certainly have involved building a completely new nose for an existing aeroplane.

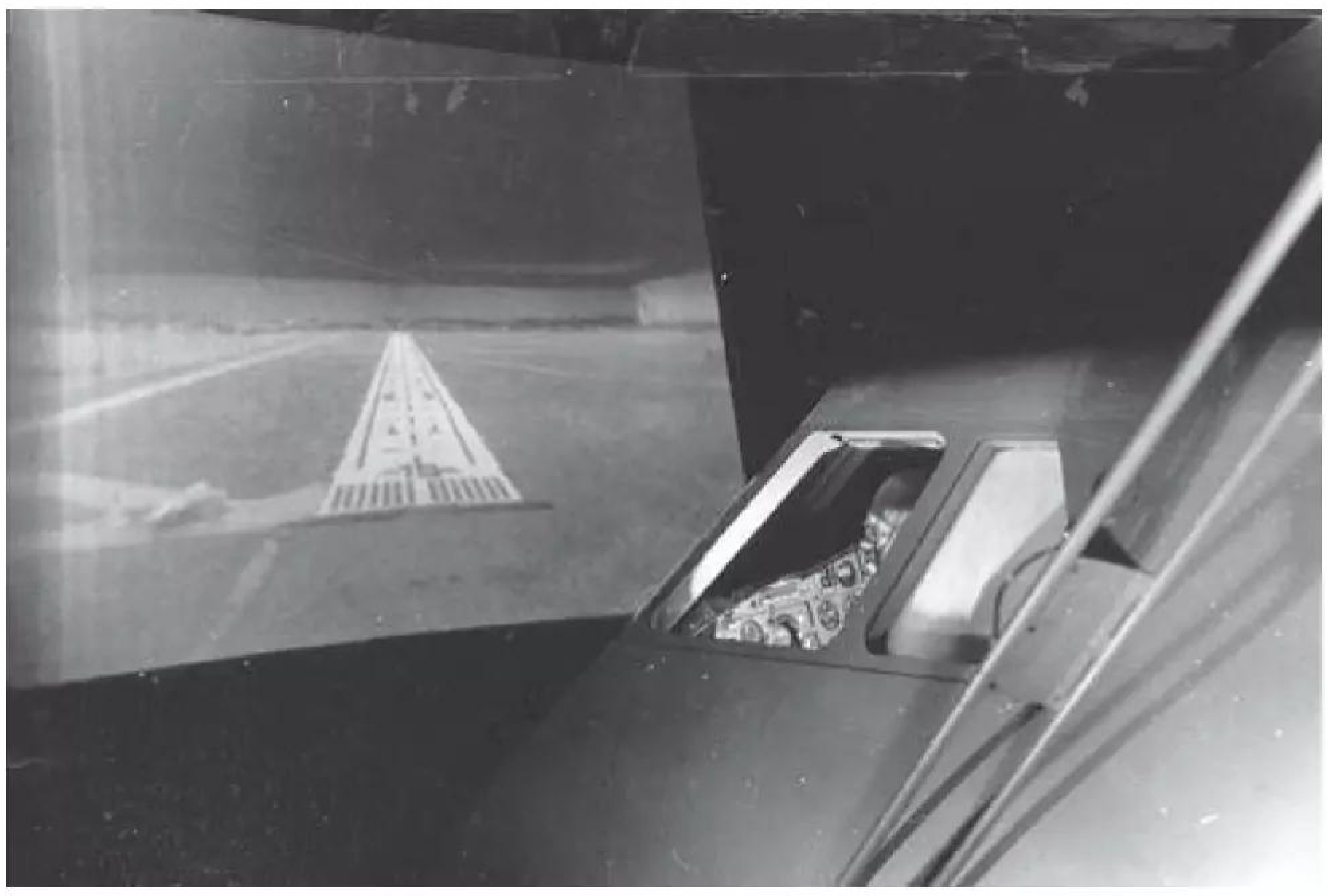
On both versions of Concorde's nose (the prototype's solid visor and the production aircraft's transparent form) the complete nose section forward of the windshield (including the visor and its mechanism) was hinged downwards. The revised visor was built around a central 'spine' with three clear panels on each side and it could be moved independently from the drooping nose. Operating time was reported to be 6 seconds to lower the visor, 12 seconds to lower the nose and 19 seconds to raise the whole ensemble. The hydraulics for such a critical set of components were of course duplicated.

All these modifications, however, added weight to the nose and this eventually required a modification to the end fuselage and rear to compensate. In 1999 Dudley Collard of BAC recalled that "the first pre-production aircraft represented an interim stage. For commercial reasons the cabin length was increased and a new rear fuselage designed. The production batch was laid down by BAC at Weybridge in time for pre-production aircraft 101 to be rolled out at Bristol in 1971."

The revised rear fuselage was to be integrated into Concorde 102, the second pre-production aircraft, which received its new nose in early 1972 and this made it the first machine to have the complete 'production' fuselage (airframe 102 was also the first aircraft to receive the new 'eyelid' type engine thrust reversers).

FLIGHT CONTROLS AND FUEL TRANSFER

Concorde's slender delta required only primary flying controls and so there was no provision for air brakes or spoilers. The flying surfaces comprised three elevons along



‘Landing’ the ground flight simulator in Toulouse. *JC Carbonel*

each wing trailing edge while the rudder came in two halves. To maintain precise control at supersonic speeds a facility for active changes of ratio between the elevons was available for different speeds, and at supersonic speeds only the innermost elevons (attached to the stiffest part of the wing) were still active.

To accommodate the rearwards shift of the centre of pressure when the aircraft passed its critical Mach number, and the consequent pitch down moment if the centre of gravity had been kept in the same position, the centre of gravity was moved by changing the distribution of the fuel along the aircraft. In essence the fuel was used as an auxiliary trim control but the alternative would have been the fitting of trim controls which at high speeds would have dramatically increased drag. During transonic flight the centre of pressure was to be moved aft, and then forwards again when slowing to subsonic flight.

BAC had the job of designing this complex fuel system. In all there were 17 fuel tanks but at take-off the tank to the rear of the wing trailing edge would be left empty. Then during the transonic acceleration phase fuel would be transferred to this tank to provide the necessary alteration in balance (and to stop the passengers having their drinks thrown into their laps by the pitch down movement). Fuel burnt during the take-off and climb part of the flight would ensure that adequate tank capacity would have become available to perform the transfer. The prototypes had a fuel capacity of 21,890gal (99,532lit) but production machines had a maximum load of 26,330gal (119,720lit).

The fuel system also acted as a heat sink to dissipate the surplus heat produced by the air-conditioning and other hydraulic systems. Due to the sequence of the fuel transfer from the main tanks, the temperature of the fuel leaving the collector tank was kept down to about 80°C. The maximum permissible engine fuel pump entry temperature was 150°C. Concorde’s maximum speed of Mach 2.2 made it possible to use standard aviation kerosene and to dispense with the need for fuel pre-cooling and for the insulation of the fuel tanks from the aircraft skin.

L.M.T.
Concorde

Four Air France pilots in front of the Toulouse simulator. *JC Carbonel*

FLIGHT SIMULATION (JC CARBONEL)

A digital simulator called the SudSim was installed in Toulouse in June 1966 and this began operating during the following October. In December 1967, after many months of tests, it was confirmed that the SudSim gave satisfactory results and that allowed pilots G. Corps of the British Air Registration Board (ARB) and Gilbert Defer of CEV to begin true simulation ‘test flights’ for Concorde prototype 001.

Initially three simulators were used for Concorde support, the Toulouse SudSim, one at Istres and another

The ‘map’ used by the Toulouse flight simulator. *JC Carbonel* at Filton. The Toulouse flight simulator originally featured only the pilot and co-pilot positions but later was extended to simulate the complete Concorde flight deck seating and fittings. A Redifon 3-axis motion system provided movement while a closed-circuit colour TV system presented a rendering of the Toulouse area as seen from the front windscreen.

The system was controlled by a DDP 224 digital computer built by the Computer Control Company (this company was sold to Honeywell in 1966). Considered by the pilots as "the best visual aid [they had] ever seen", it was nevertheless inadequate for the visual part of the approach and here the pilots had to rely on their instruments. This was accepted as a "limitation of this sort of simulation", but was later to cause friction between BOAC and BAC because BOAC had previously suffered a bad experience with a simulator using a TV system; the airline wanted instead to use the VAMP (Variable Anamorphic Motion Picture) system provided by Link Simulation and Training.

The main objectives of all of these simulations were to assess the flying aircraft's qualities and to study the crew workload, systems management and integration of the aircraft into traffic; flight test crew training had only third priority. A test aircraft, the variable stability Mirage IIIB, was also used to calibrate the response of the simulator in regard to the flying qualities aspect during four simulated flights made between 3 and 27 December 1968.

Sud took charge of the general operation and of the flying qualities study programme while BAC looked after crew workload. Preparation through flights in the simulator was deemed necessary for airline pilots before they would be allowed to fly Concorde prototype 001. This course was completed by actual flights in 'delta' aircraft (read Mirage). The Toulouse simulator was still in use in 1975 as part of the initial training for the British Airways and Air France pilots, in particular to prepare them for what was called the 'endurance programme'.

Later in June 1970, and despite the fact that Concorde was by now flying, further simulation tests were carried out at the Ames Research Center in America in cooperation with the ARB and NASA. The CEV crew for this programme was Commandant Defer and flight engineers Cavin and Guyot. The idea here was to simulate the prototype Concorde's behaviour at low speeds and low heights to see if it was compatible with US and European regulations.

Simulated flights were made on 4, 5, 8 and 9 June with a concluding meeting held on the 12th and the conclusion was that the security regulations, in particular in regard to landing speeds and climbing gradients, were particularly compatible with Concorde.

HIGH ALTITUDE TURBULENCE

Concorde was intended to fly at altitudes well above those at which subsonic jets operated and in doing so would then be well above most of the turbulence likely to be present on its flight route. However, it was appreciated that research into high altitude turbulence would still be required. In fact, besides turbulence it would be necessary to know the intensity and frequency of aspects such as the wind, clouds, ice particles, raindrops and hailstones found within the Concorde operational height band and also steep gradients of temperature. The difficulty here was that it would not be possible to acquire this data without using aircraft which possessed long endurance and which were fitted with special equipment to take meteorological measurements at such heights. Many sorties would also be needed to establish the facts with any reasonable certainty.

The Meteorological Office had realised as early as 1962 that, if supersonic passenger flight was to become a reality, it would be asked to provide statistical information of this kind up to heights of at least 70,000ft (21,335m). As late as 1965 the Meteorological Research Flight at Farnborough had just one suitable aircraft capable of investigating turbulence up to about 48,000ft (14,305m) and in good conditions (English Electric Canberra PR.Mk.3 serial WE173). Higher performance aircraft instrumented for turbulence investigations were also available at RAE, but their effective ceiling was still only around 50,000ft (15,240m) and of course they were not concerned specifically with many of the aspects of the SST operation.

When it became evident that the RAF would not have an aircraft capable of taking measurements at heights up to 70,000ft (21,335m), questions were asked on 28 August 1964 if there was any other aircraft in the Ministry of Aviation fleet which might be suitable or, alternatively, if any other solutions existed. The American Lockheed U-2 spy plane was mentioned in this connection, as was the possibility of loaning or even buying a Martin RB-57F high altitude reconnaissance aircraft to undertake the work.

There was indeed some concern that it might not be possible to collect all of the necessary data before Concorde would itself begin flying. In addition, at a meeting held at the Ministry of Aviation on 11 May 1964 the representative of the Air Registration Board had stated that without this meteorological information it would not be possible to certificate the Concorde for passengers, and that if there were no alternative aircraft then the Concorde itself would have to be employed to acquire it.

Over the next year there were frequent discussions with the French and Americans and in particular with the FAUSST Franco-Anglo-US working group, through which the Meteorological Office had been able to offer advice on an American project called Hi Cat (Cat – clear air turbulence) that also looked into this subject. Although the Americans had the advantage of possessing the U-2, which could cover the relevant height band and was instrumented for meteorological observations, it was not the ideal aircraft to investigate turbulence.

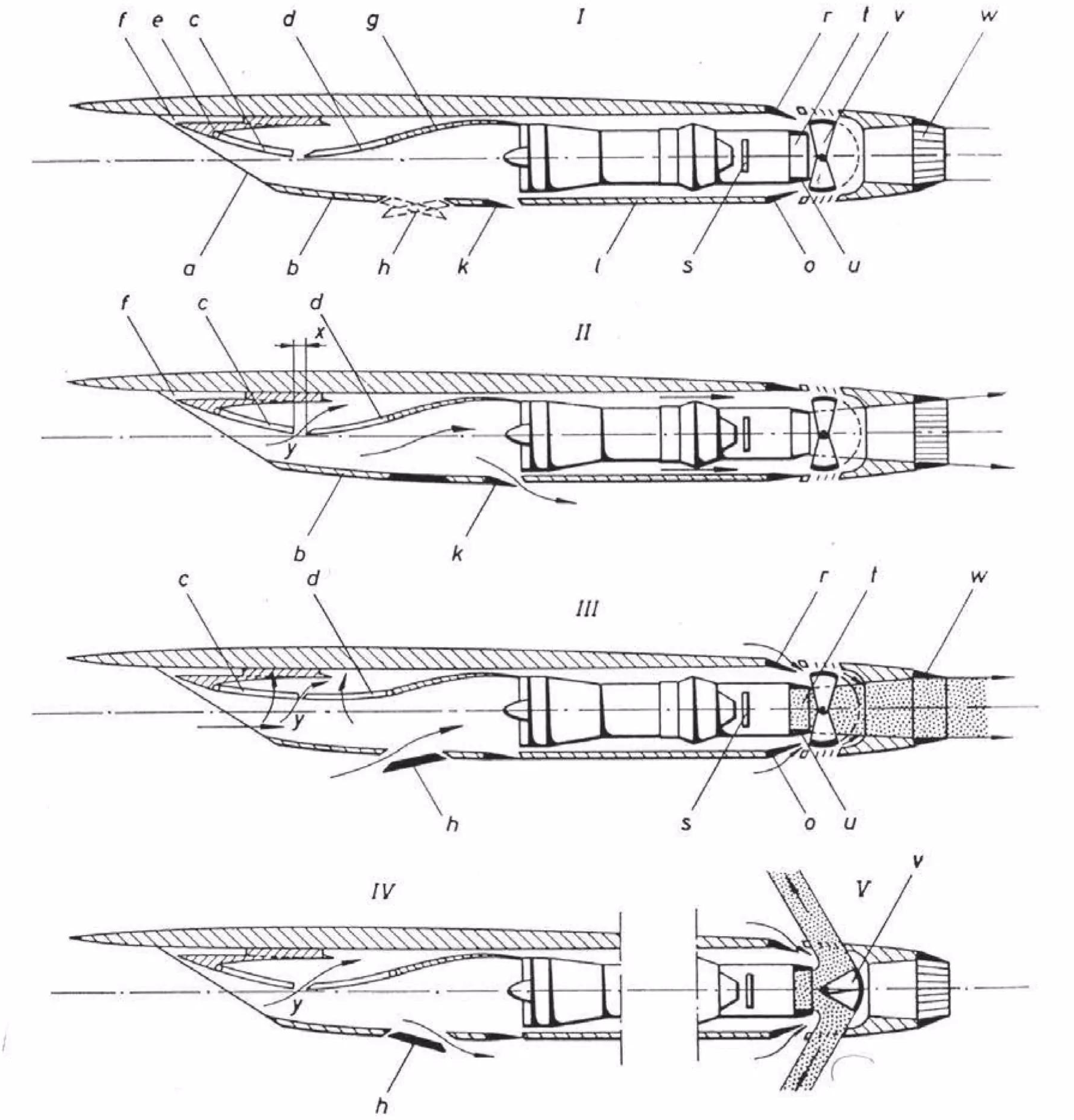


Fig. 25. — Coupe longitudinale de la nacelle

I : aspect général; II : en croisière supersonique; III : au décollage avec réchauffe;
IV : en cas d'arrêt d'un moteur en vol; V : à l'atterrissage avec inversion de la poussée
a : entrée de manche à air à coupe oblique; *b* : fond courbe fixe; *c* et *d* : rampes mobiles; *e* : lèvre fixe;
f : piège à couche limite; *g* : manche courbe; *h* : volet auxiliaire; *k* : clapet de décharge; *l* : paroi sous le moteur;
o et *r* : prises d'air tertiaire; *s* : support de brûleurs pour la réchauffe; *t* : cône primaire d'éjection; *u* : silencieux;
v : inverseur de poussée; *w* : divergent à géométrie variable; *x* : fente; *y* : air de la couche limite de la rampe

Cut-away drawings of the Concorde engine nacelle. The five drawings show:- I: general appearance, II: the set up in supersonic cruise mode, III: take-off with afterburning, IV: stopping an engine in flight, V: landing with reverse thrust. The variable intake ramp ensured that the maximum pressure recovery was available under all flight conditions. Besides altering the throat area, the ramp would adjust the pattern of shock waves by which compression of the air was achieved in the intake mouth at supersonic speeds. A rapid acting spill-flap in the diffuser of the intake would spill variable quantities of air during supersonic flight in order to balance any difference between the air mass flow supplied by the intake and that required by the engine. An auxiliary door was also provided in the lower surface of the intake to maintain the geometrical position of the normal shock wave when there was a large variation of the engine air flow. Operated in the opposite sense, at low speeds this also provided an effective increase in area which enabled the intake to operate more efficiently during ground runs, take-off, and in low speed flight. *SNECMA via JC Carbonel*

An Olympus 593 shown here in a sling. Examples were ground run at a dry thrust of nearly 33,000lb (146.7kN) and at 37,000lb (164.4kN) with afterburner. Concorde's engines were in fact tested at thrusts in excess of the aircraft's power requirements years before it went into airliner service. *Bristol Siddeley*

However, by August 1966 a solution had been found after it had been agreed that the UK's altitude meteorological research would be conducted using Canberra PR.Mk.9 aircraft. One example had already started on a programme and it was possible that a second might be employed on a complementary programme. In addition France was contributing with tests using the Dassault Mirage IV while close touch was kept with various programmes in the USA.

Finally, those Concordes to be used in the development programme, and on route proving trials, would also provide extremely valuable information on the meteorological conditions experienced at high altitude. Extensive discussions regarding these various programmes had been held between the Meteorological Office and the Air Registration Board, who were now satisfied that this research would be adequate to ensure that Concorde would be able to enter airline service in 1971 without serious restrictions.

HUMAN FACTORS

The recognised human limitations or passenger tolerance to be taken into account for normal subsonic passenger aircraft included G-forces, angles of bank, cabin floor angle, cabin altitude and rates of climb and descent. The introduction of supersonic operations would involve additional factors which might either effect passenger comfort or limit the degree of operations due to physiological or psychological reasons. Therefore, research information would be required on the effect of, and passenger tolerance to, such factors as aerodynamic heating on cabin temperature, windowless aircraft (if this was the chosen direction), and possible restrictions on the freedom of movement within the cabin.

There were also concerns about the exposure to radiation. Concorde's high cruise altitude would mean its passengers would receive nearly twice the flux of radiation (the quantity which passes through a surface or substance) to those travelling on a normal long-haul subsonic flight. So there might be an increase in the threat of skin cancer, and there was some anxiety that passengers, particularly children and pregnant women, might be exposed to unjustifiable risks. However, calculations eventually showed that, due to the proportional reduction in flight time, the equivalent dosage overall per supersonic flight would normally be less than that experienced by passengers taking a conventional flight over the same distance.

NAVIGATION AND SYSTEMS

A new airliner would need a complete mix of systems and equipment including the electrics and hydraulics to operate the flying surfaces, controls and undercarriage, while a large batch of avionics would be necessary for example to provide navigation. And to ensure the safety of the aircraft and its passengers there had to be extensive back up systems. For example, Concorde was given four different ways of lowering its landing gear, two of which used separate hydraulic sources while a third employed compressed air and the fourth saw the undercarriage dropping down by its own weight. In addition, every possible combination of failures in flight and on the ground had to be explored and the requisite back up systems developed for them.

In mid-July 1964 meetings were held at Sud in Paris to discuss what navigation equipment should go into the airliner. At this stage the proposed installation for production Concordes consisted of: 3 x inertial navigation systems, each comprising a platform and digital computer; 1 x flight director computer; 2 x instrument landing system (ILS); 2 x DME indicators (Distance Measuring Equipment); 1 x marker receiver; 1 x cloud-collision radar and 1 x radio altimeter. There was also to be space provision for Loran 'C' (long range navigation) or any such other long range aid as might be accepted by ICAO as an international standard.

Sud also stated that the prototype aircraft would carry a navigator on all flights. A twin-Doppler installation would be tested on the prototype, principally as an insurance policy against unforeseen difficulties arising in the inertial system. BAC stated that it had canvassed the opinion of potential buyers with respect to the installation of Doppler equipment and only BOAC had said that it thought this would be necessary; three of the others airlines consulted had said that they definitely would not fit it, and three said that they hoped they would not have to fit it. However, Sud

The BAC-SNECMA team at Santa Anna in front of an early model of the 'eyelid' thrust reverser. On the right is Jean Calmon who was the team leader for the collaboration work with Tool Research and Engineering of Beverley Hills. *Espace Patrimoine Safran*

confirmed that there would be no optional fit of Doppler in production aircraft.

POWERPLANT – UK

Concorde's powerplant had four Bristol Olympus engines at its core, but sustained Mach 2 cruise meant that the entire powerplant installation – air intakes, engine and exhaust – would have to contribute to make it work efficiently and effectively.

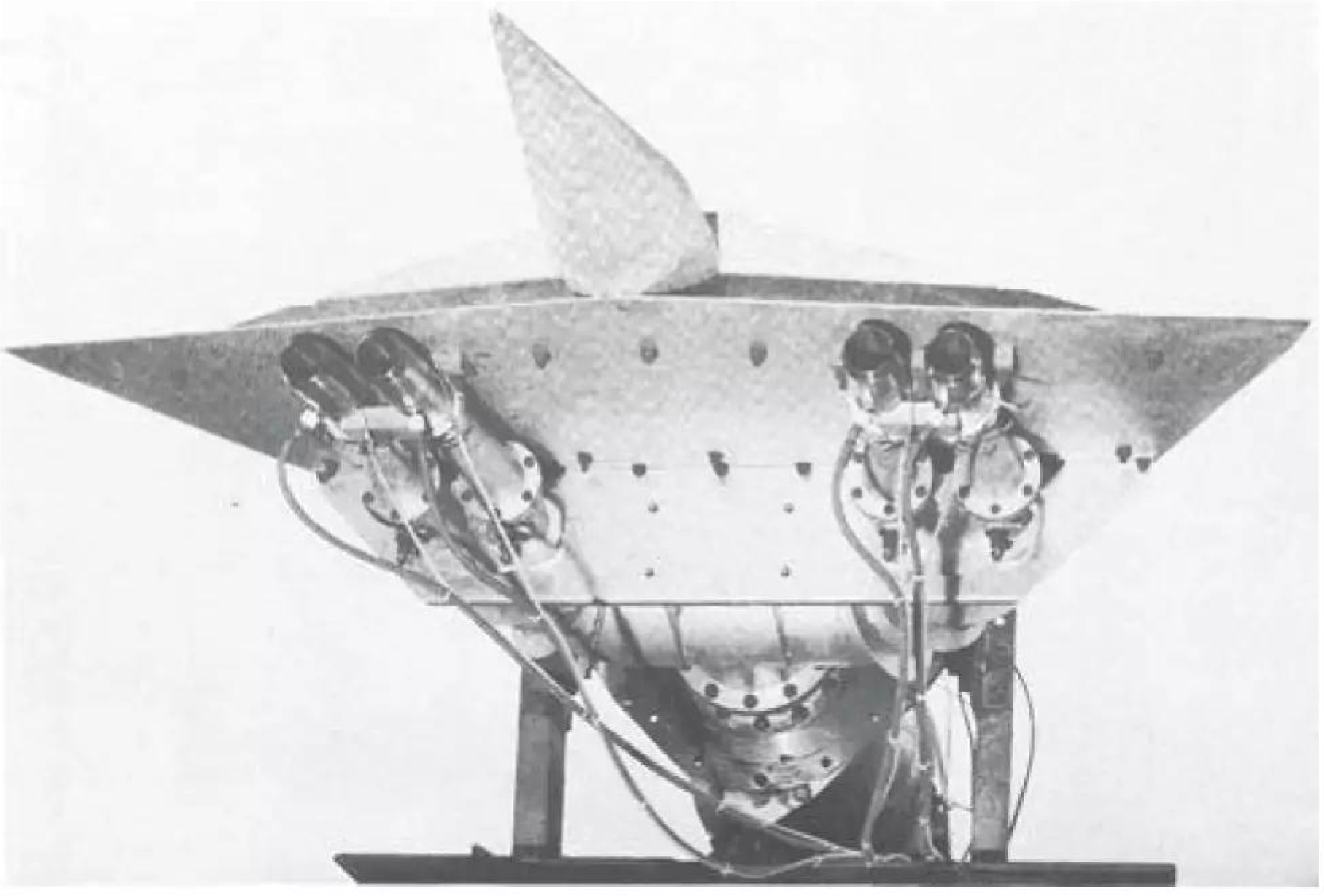
The initial version of the Concorde Olympus was called the 591 and was a civilian development of the TSR.2's Olympus 22R, and the 22R was designed only for a brief sprint at Mach 2 which burned a lot of fuel.

A modification which introduced a zero stage on the front of the low pressure compressor was then called the Olympus 593. In due course, however, a major redesign of Concorde became necessary to improve its range and this resulted in a higher all-up weight.

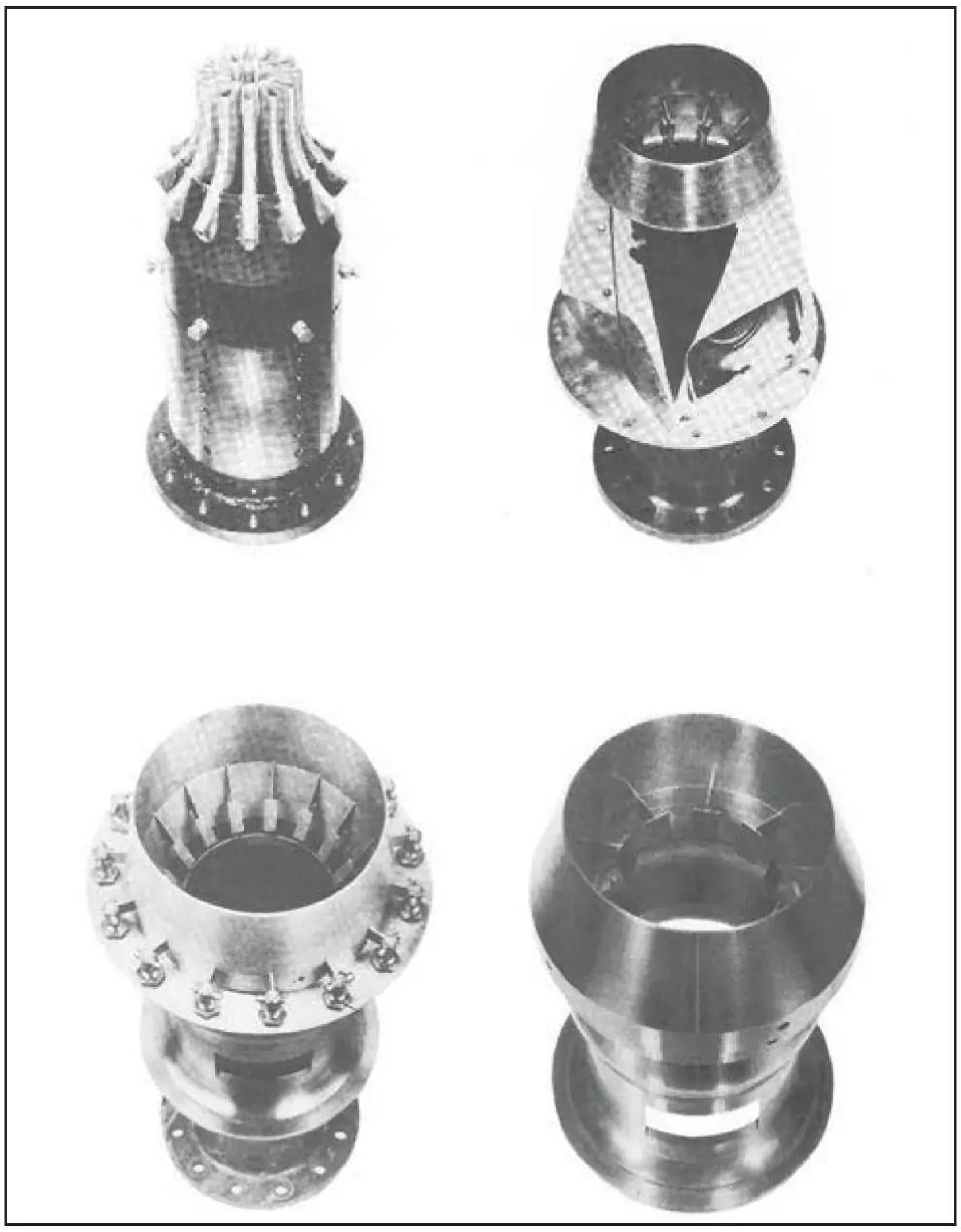
More thrust was therefore needed so a full redesign of the 593 was made based around new compressors and turbines. In 1964 the original version was redesignated 593D (D for derivative) while the later form was called the 593B (B for big, because it was physically larger than the D). Olympus 593B's dry thrust was 32,800lb (145.8kN), increasing to over 38,000lb (168.9kN) with reheat.

Early SST studies had tended to show a row of engines in a tight group at the rear of the aircraft, but by the time Super Caravelle and Concorde were being considered the best solution was thought to be four engines with two under each wing. Concorde's four engines had air supplied through fully variable quasi two-dimensional intakes.

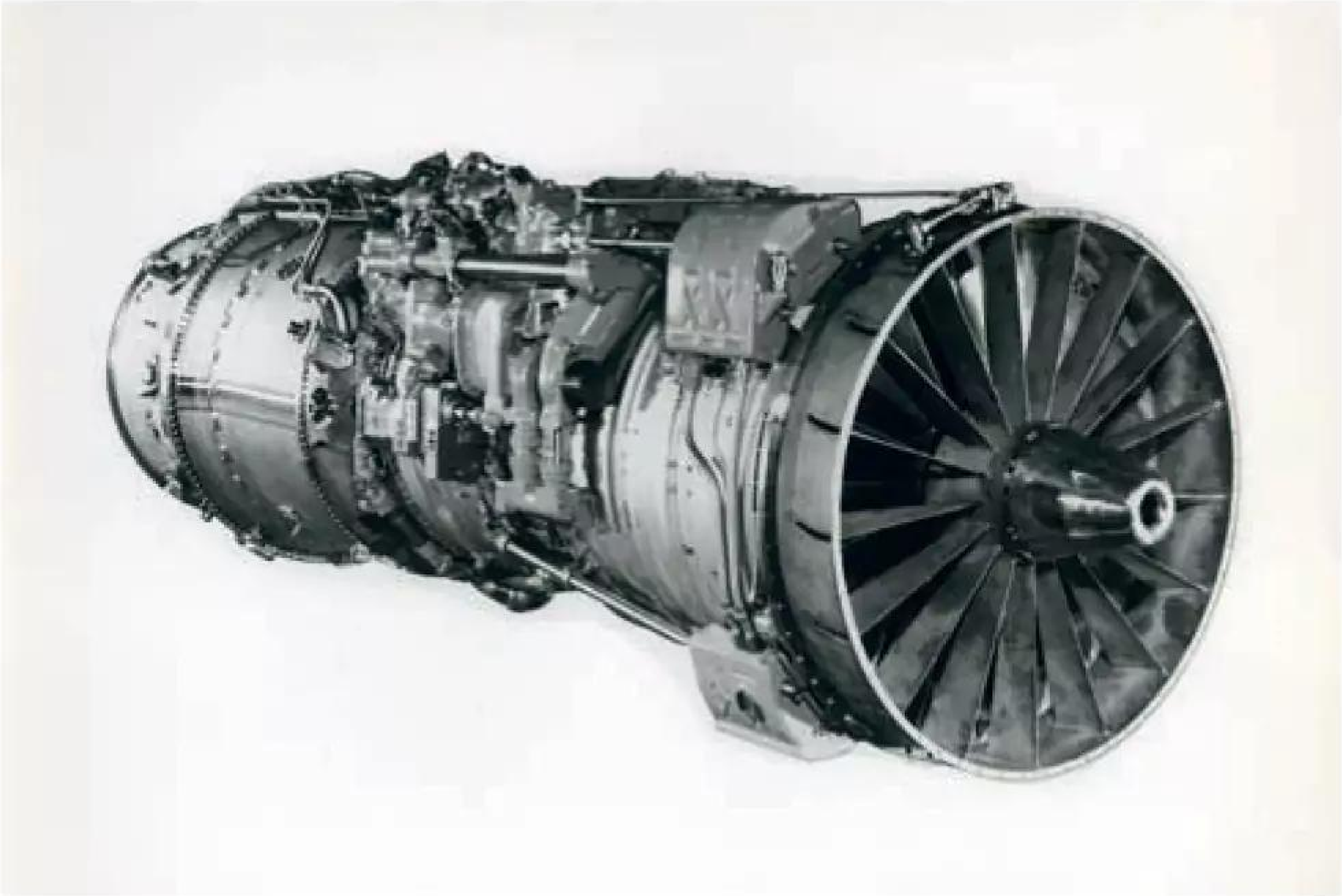
An optimum entry flow was maintained in different flight conditions by adjusting the intake ramp geometry, with some additional fine adjustment being made using a controlled bypass bleed. Test facilities at ONERA and CEP in France, and at the NGTE, RAE and ARA in the UK, also helped in refining the detail design of the intake and its control system, which proved to be one of the fundamental issues behind the success of Concorde when flying for prolonged periods at Mach 2. This feature is described superbly in the Rolls-Royce Heritage Trust publication *Olympus: The First Forty Years* by Alan Baxter.



A model designed to simulate and investigate on a 4-engine SST the 'array effect', the dispersion of sound to the side during a fly-over. *Espace Patrimoine Safran*



Models of different nozzles which were tested by SNECMA during the design phase of the Concorde rear engine section. *Espace Patrimoine Safran*



Another view of an Olympus 593 engine.

"To achieve optimum operating performance, a jet engine needs to be supplied with air at a local Mach Number of about 0.5 at the engine face, and this should be maintained irrespective of whether the aeroplane is flying at low speed close to the ground or cruising at Mach 2 in the stratosphere. A simple intake cannot achieve this as at supersonic speeds shockwaves, if not carefully controlled, can move down the intake throat causing severe distortion and loss of efficiency. The complexity of a variable intake is necessary to ensure that the engine is supplied with the correct amount of air at the correct Mach number at all times, in other words it ensures that the mass flows of the engine and intake are correctly matched for all phases of flight.

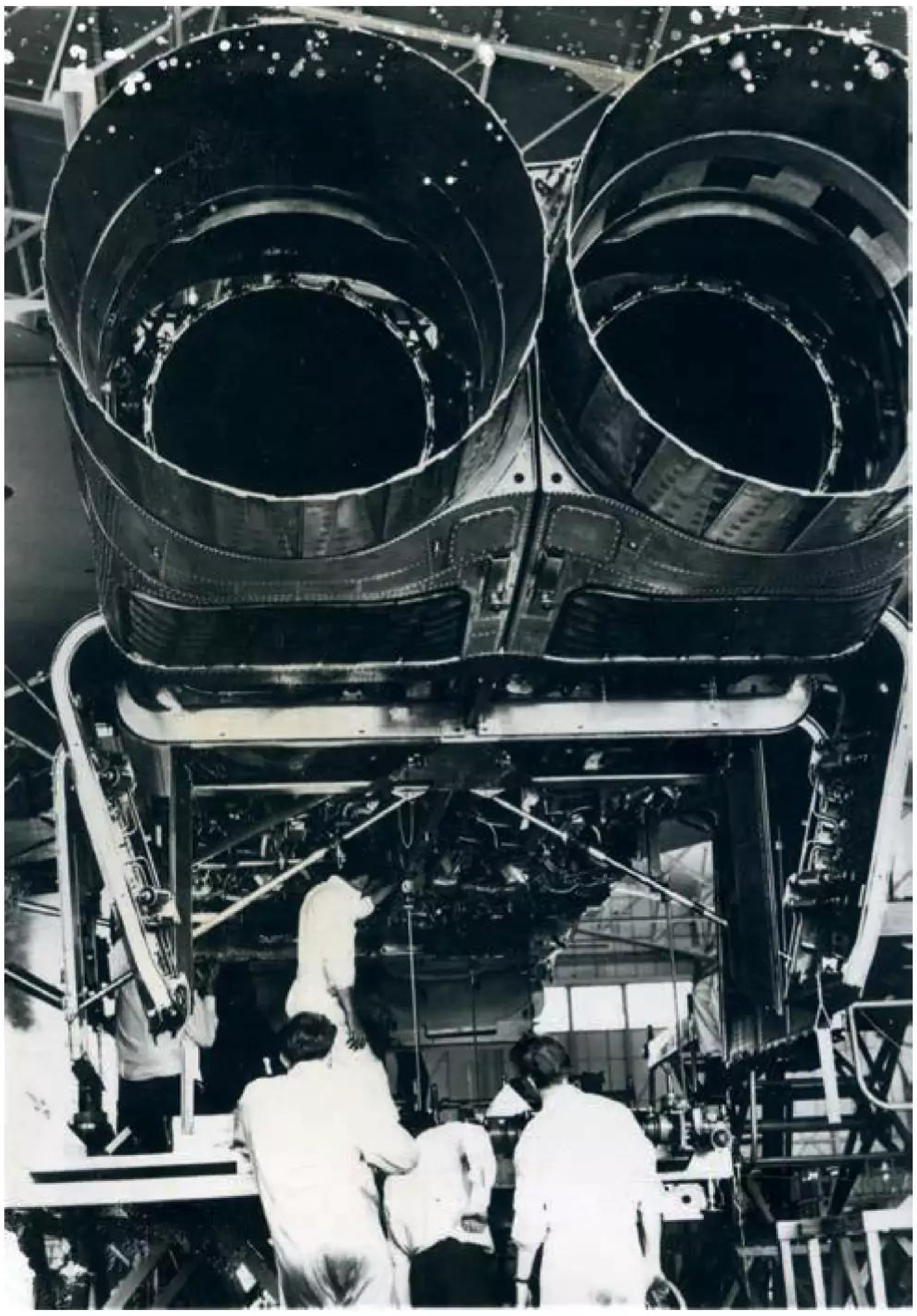
The Concorde nacelle was designed with a two-dimensional external compression intake. That is to say all the shockwaves generated by the sharp leading edges remained ahead of the intake, the velocity of the air being reduced to about 0.9 Mach number. The intake throat had a variable convergent-divergent section formed by the front and rear ramps, between which was an air bleed used to control the position of the shocks. There were four shockwaves, the last attaching to the lower lip of the intake and never inclining any further rearwards than the trailing edge of the front ramp. An auxiliary intake was fitted in the intake floor, which also had the function of dumping excess air during periods of low engine demand."

This arrangement meant that when Concorde was cruising at Mach 2 the power was generated as follows: -12% from the variable inlet ramp (due to drag), +75% from the air intake system, +8% from the engine itself, and +29% from the convergent/divergent nozzle. So at Mach 2 the great majority of the thrust came from the air inlet arrangement while the engine essentially just kept the airflow moving and everything 'ticking over'. With such an extraordinary balance between these items, it was no surprise that the aircraft's inlet and nozzle detail design absorbed at least as much development time as did the basic Olympus unit.

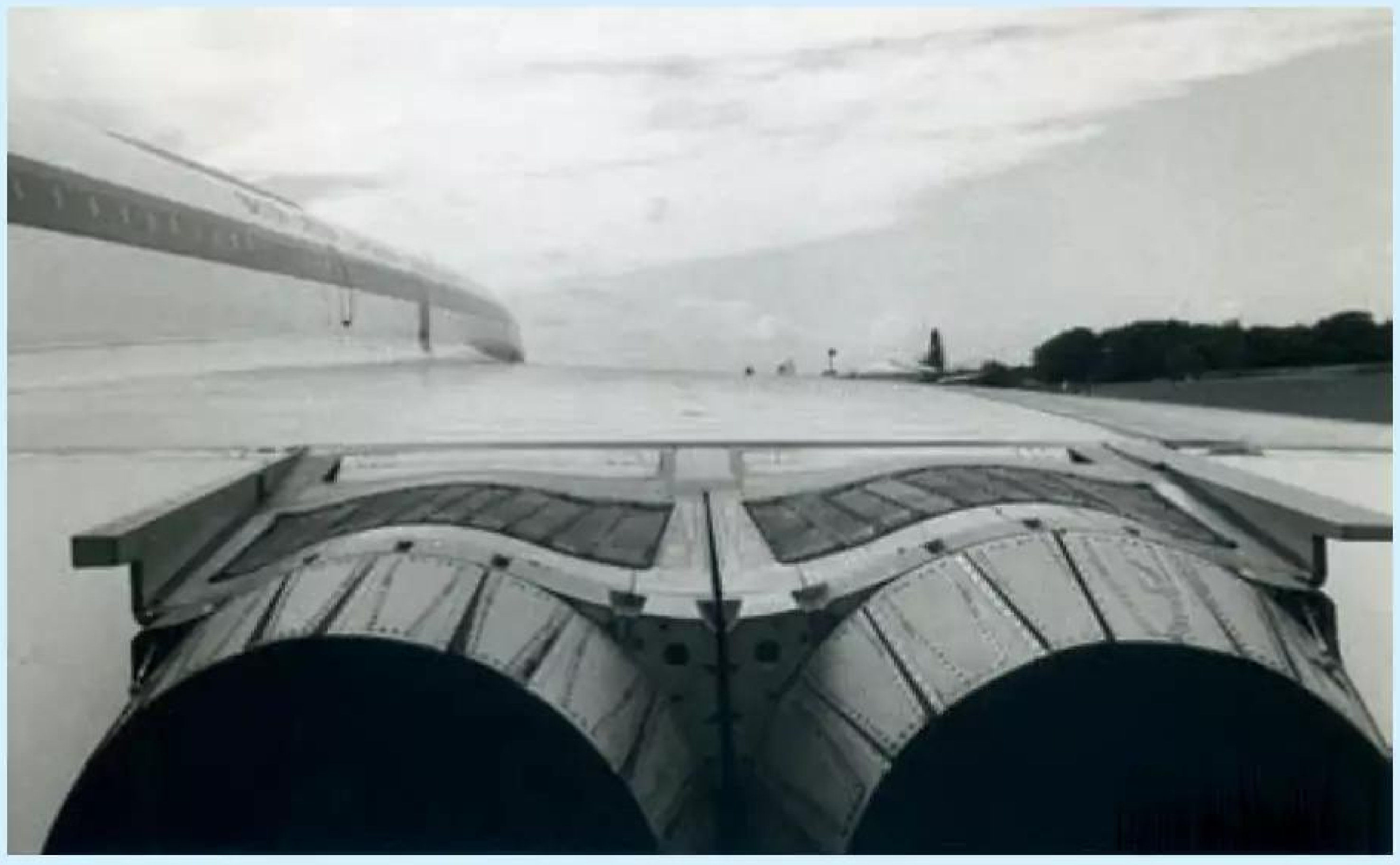
Cruise at Mach 2 raised the potential for new problems. For example, even a minor disturbance in the airflow could result in a surge where the high-pressure air in the combustion chamber would reverse its direction to come back out through the compressor and the air intake, serious enough at subsonic speed but a noisy, violent and indeed terrifying occurrence at Mach 2. In fact, when this phenomenon was first encountered with Concorde 001 its No.4 engine suffered structural damage. More detailed research followed which eventually cured the problem, and as part of the trials programme one Olympus 593 was surged deliberately around 800 times and continued to run satisfactorily.

Equally worrying was the potential loss of an engine. When an engine fails on a subsonic aeroplane thrust is lost on that side, but the 'dead' engine also creates drag which makes the aircraft yaw and bank in the direction of the failed unit. If this were to happened on Concorde at Mach 2 it might rip the airframe apart.

However, flight testing enabled a technique to be developed where Concorde's pilot could shut down both engines on the same side at Mach 2 without experiencing any problems. With the engine out of action little or no air was required from the intake, so an engine failure could be



Engine jet pipes on one of the Concorde prototypes.



Two photos showing the jet pipes and upper wing of pre-production Concorde 101 G-AXDN.

countered by having the auxiliary spill door opened and the ramps fully extended. This would then deflect the incoming air downwards past the engine, while in the process increasing lift and keeping drag to a minimum.

Two examples of the '593D' were built for ground tests at Patchway and the first of these first ran on the bench in July 1964, while the second recorded a thrust of 28,100lb (124.9kN) to become the highest dry thrust rating achieved by any turbojet so far. One of the 593Ds was eventually sent to France's engine research centre at Saclay. In the meantime, SNECMA had produced the exhaust system – afterburner, variable convergent-divergent exhaust nozzle, thrust reverser and silencer – and its test programme involved fitting and running a full scale nozzle assembly to an Olympus 301, the variant used by the Vulcan bomber. In flight the primary nozzle area would vary continually to ensure that the engine was constantly in tune with current flight conditions, even if the reheat was not in use.

POWERPLANT– FRANCE (JC CARBONEL)

As noted earlier, the Government agreement defined SNECMA's role in the design and development of the Olympus 593 rear exhaust section, including the afterburner, propulsion nozzle, silencer and thrust reversal units.

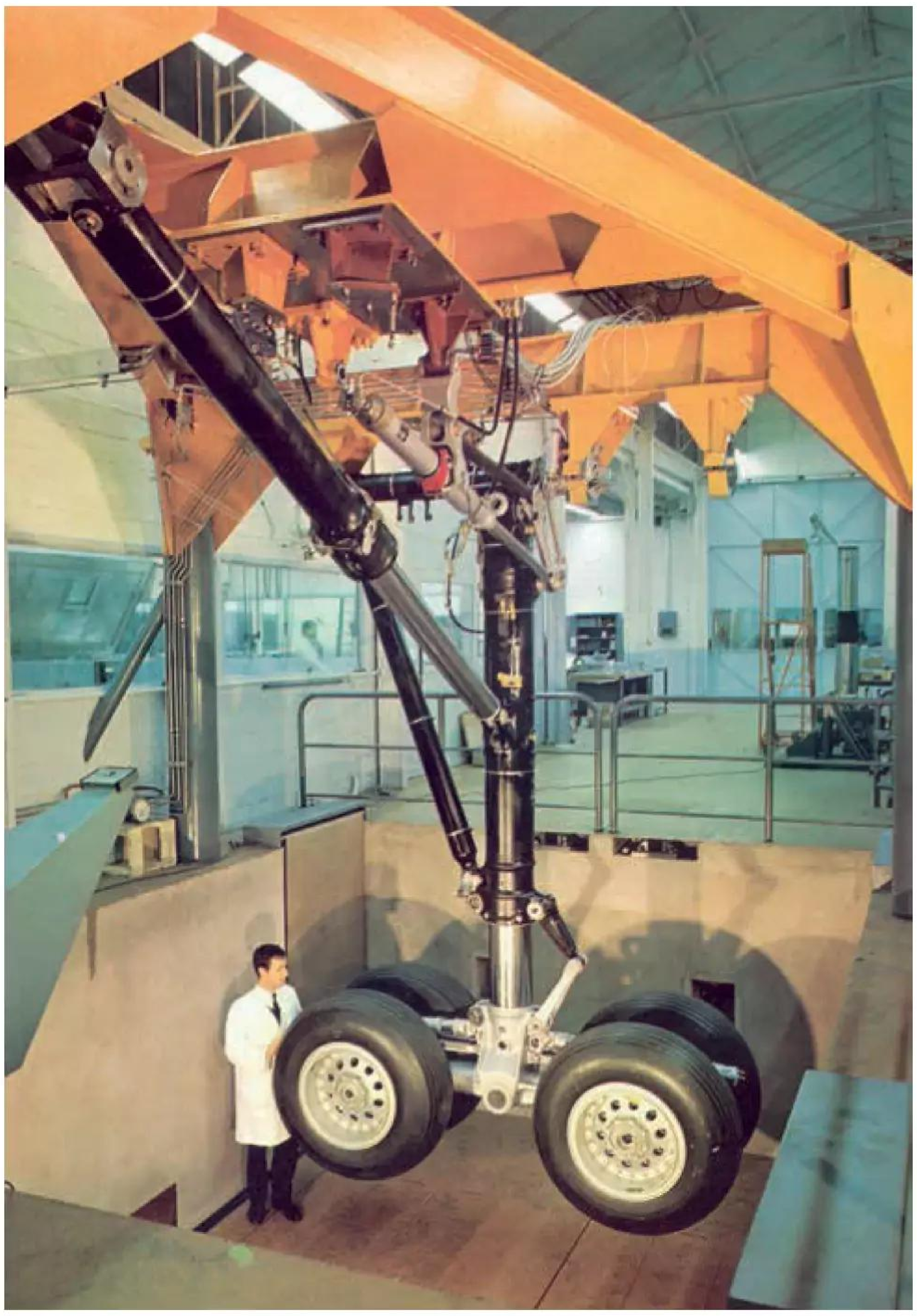
Reheat was expected to increase thrust by up to 20%, mostly for take-off. The main difficulty here was to reduce the 'cold loss' which could be induced by the supersonic speeds reached by the air flowing in the feeder channel.

SNECMA's original Type 10 propulsion nozzles were used only on prototypes 001 and 002, but an improved and lightened Type 11 was fitted to pre-series aircraft 01. Then in 1969 Sud's Etienne Fage proposed some improvements: a) reduce drag by using nozzles made in the shape of a TV screen for a better fit in Concorde's rectangular-section engine nacelles; b) use a single load-carrying structure for both engines on each side; c) control the width of the exhaust nozzle through the use of two half-shell buckets, which could also be used as thrust reversers; d) reduce weight by using a honeycomb material called Stresskin.

Stresskin was available from an American company called Tool Research and Engineering (TRE) and contacts were made by the airframe manufacturers to procure the relevant parts.

TRE was contracted by SNECMA to assist in the general design of the nozzle and a permanent French team was set up by SNECMA in California. The first buckets were delivered in April 1971 and a set of nozzles was installed at

The nose gear to be installed on Concorde prototype 001 F-WTSS undergoes testing at Messier. *Messier*

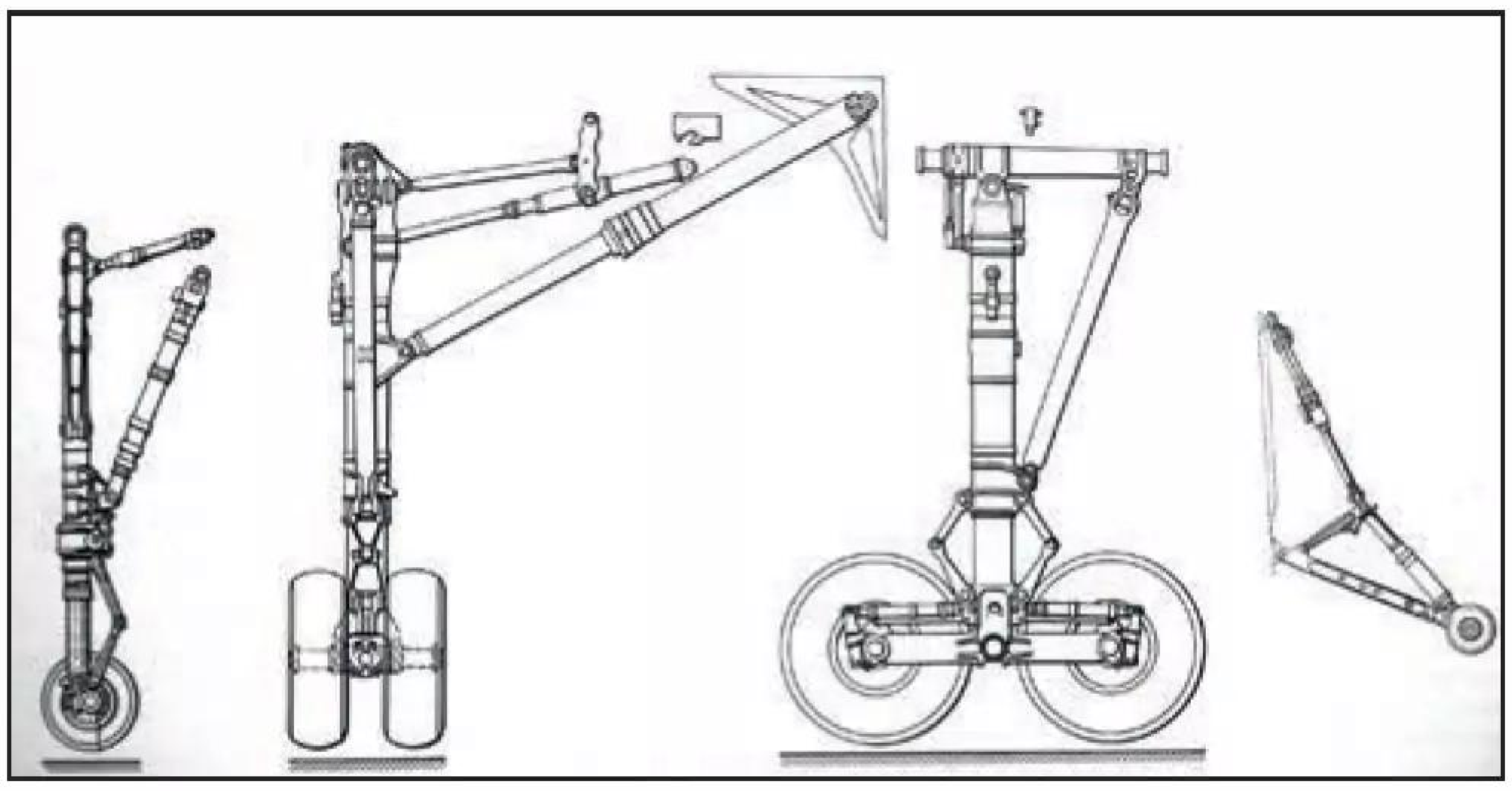


The main landing gear for 001 is tested at the Hispano-Suiza factory. *Hispano-Suiza*

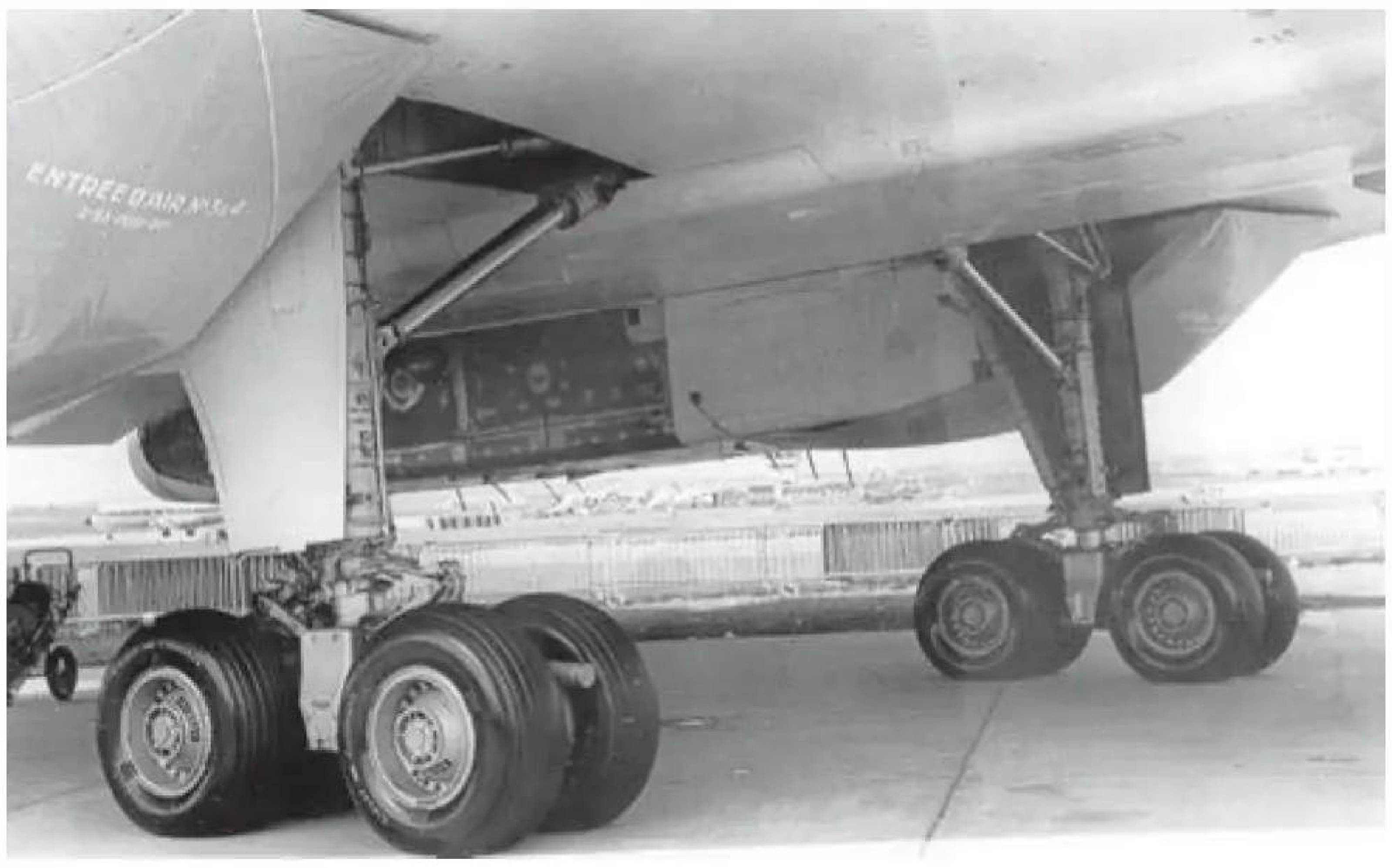
CEP Saclay in September. The new 'eyelid' nozzle (SNECMA Type 28) was first installed on pre-series Concorde 02 during 1972, but in the end this technological improvement increased the Concorde payload by only 2,000lb (907kg) when Etienne Fage had originally hoped for a gain of some 8,000lb (3,629kg).

A thrust reverser was necessary to allow Concorde to operate from currently available runways. The eventual production design had two half-shell buckets rotating as a 'wolf trap' to redirect the hot air from the turbojet into upper and lower grids orientated toward the front of the aircraft, which then produced a braking action.

Due to the need for these parts to resist high temperatures, they were made in a heat-resistant nickel-base superalloy called Waspaloy. Studies were made on the impact of thrust reverser operation on the noise emitted by the engine and these proved that the Type 28 nozzle offered an advantage. During a take-off in afterburner the reverse thrust upper and lower hinged half-shells would swivel to a fairly high angle and in doing so squeeze the jet flow to make it splay out sideways; this helped to reduce the sideline noise (on the airfield) significantly at a cost of a moderate loss in thrust. On landing the buckets would rotate to the rear to deflect the exhaust for reverse thrust. In fact Concorde could use reverse thrust in the air to increase its rate of descent, although here only the inboard units were used.



Detailed drawings of the individual sections for the Concorde undercarriage. *JC Carbonel*



Close-up of F-WTSS's main landing gear. *Hispano-Suiza*

Initially the thrust reversers mounted on the first prototype, when the aircraft was still equipped with Phase 1 and later Phase 2A Olympus engines, proved troublesome as they tended to make the engine re-ingest exhausted hot air during the landing run. During the prototype's supersonic trials use of the thrust reverser system was not permitted at all during flight, and at other times it was limited in duration because its operation would take the

The tail skid on Concorde 001. *JC Carbonel*

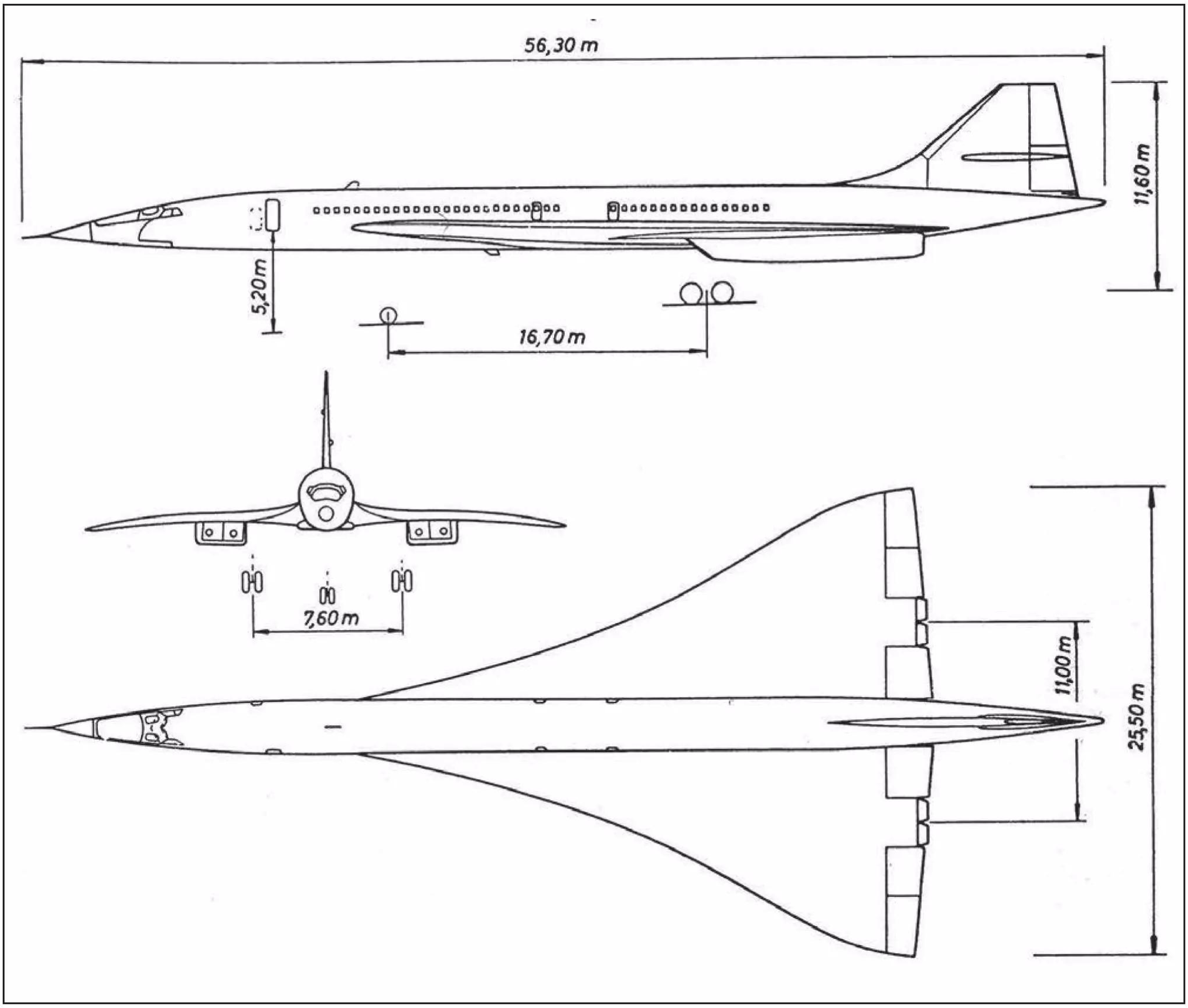
On production aircraft the tail skid was replaced by small wheels. *JC Carbonel*

temperature inside the nacelles to the maximum allowed in just 30 seconds. This early overheating of the nacelles in fact led to some internal damage and was one reason behind the subsequent 'eyelid' modification adopted for production aircraft.

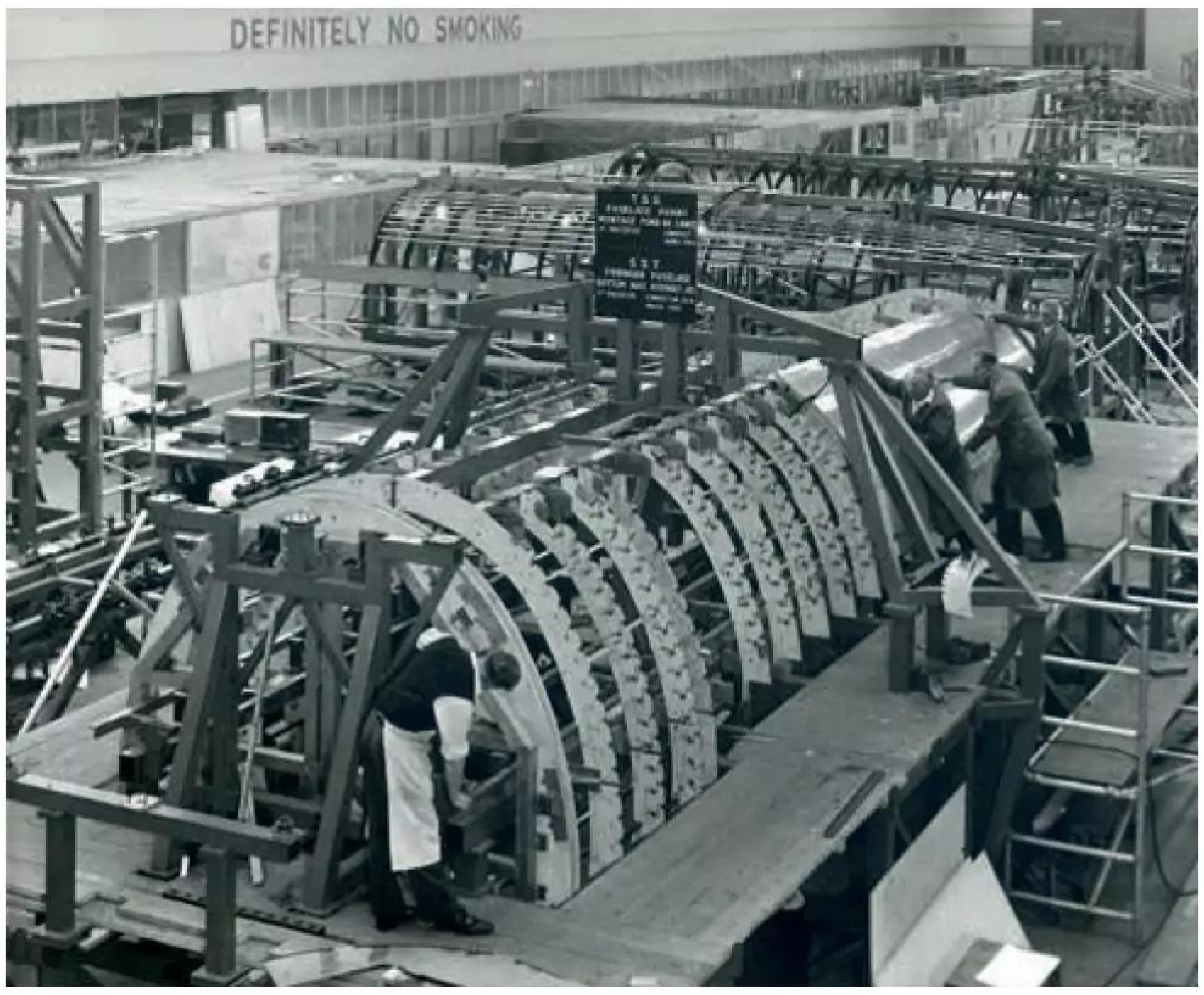
By the end of the trails programme over 11,000 hours of engine testing had been carried out using ground rigs and 17,000 hours of engine test flying completed using the Vulcan bomber test bed.

RUNWAYS

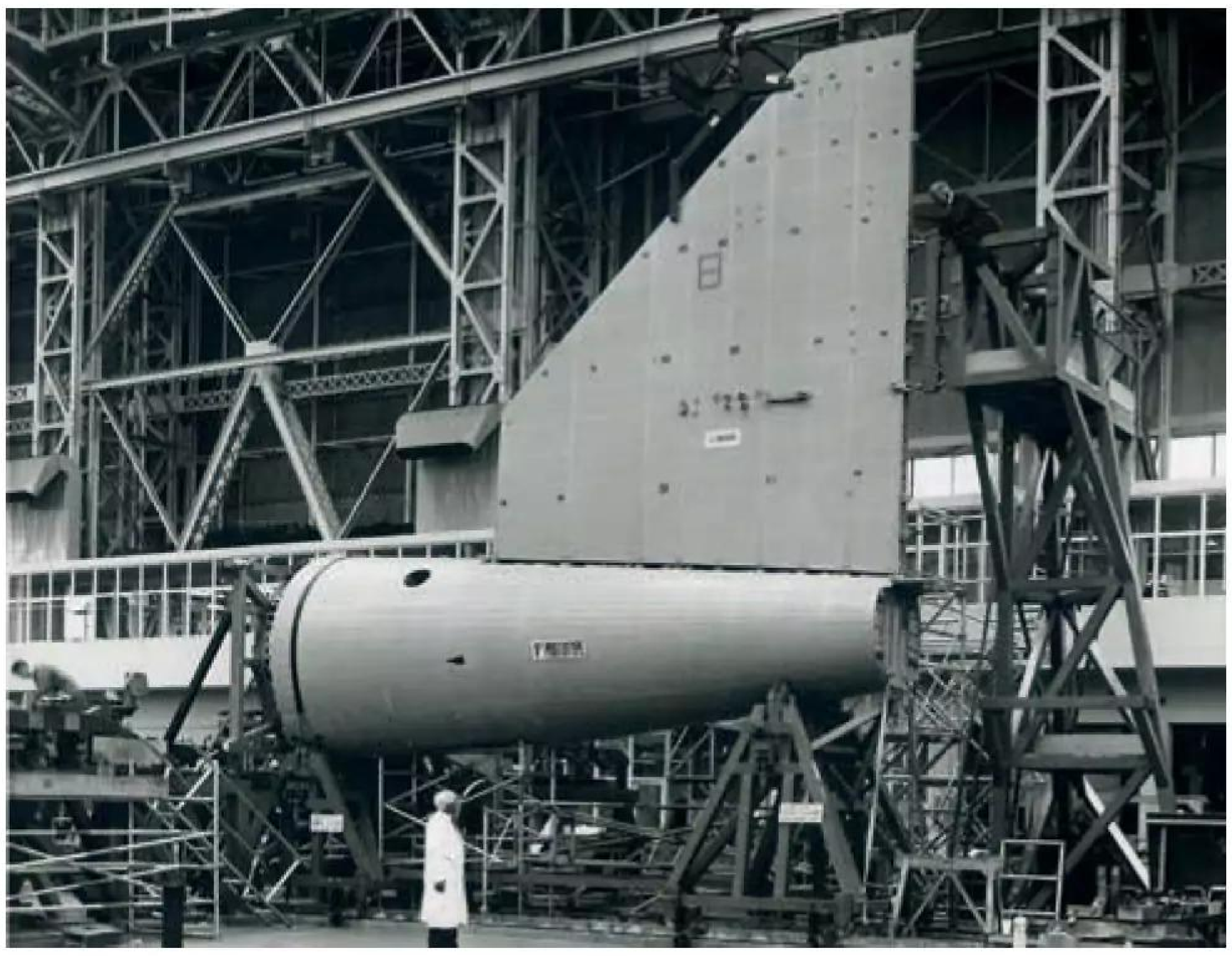
Prior to the development of Concorde there had been a tendency for some years for each new generation of transport aircraft to become more demanding on the strength and length of runways. Many existing runways had been constructed immediately after the end of the Second World War and these were not designed to cope with the severe requirements of modern jet aircraft.



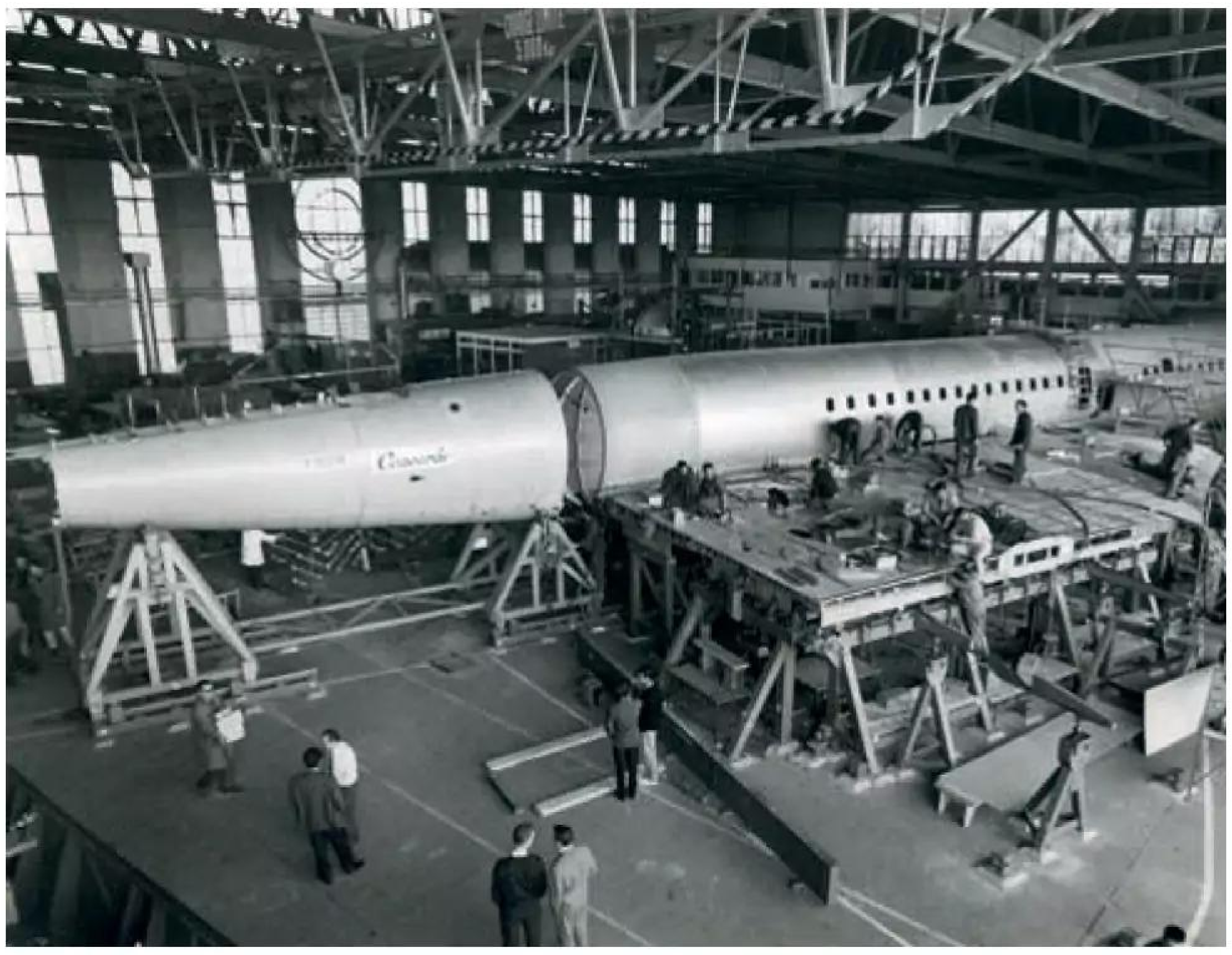
Manufacturer's three-view drawing of the Concorde prototype. *JC Carbonel*



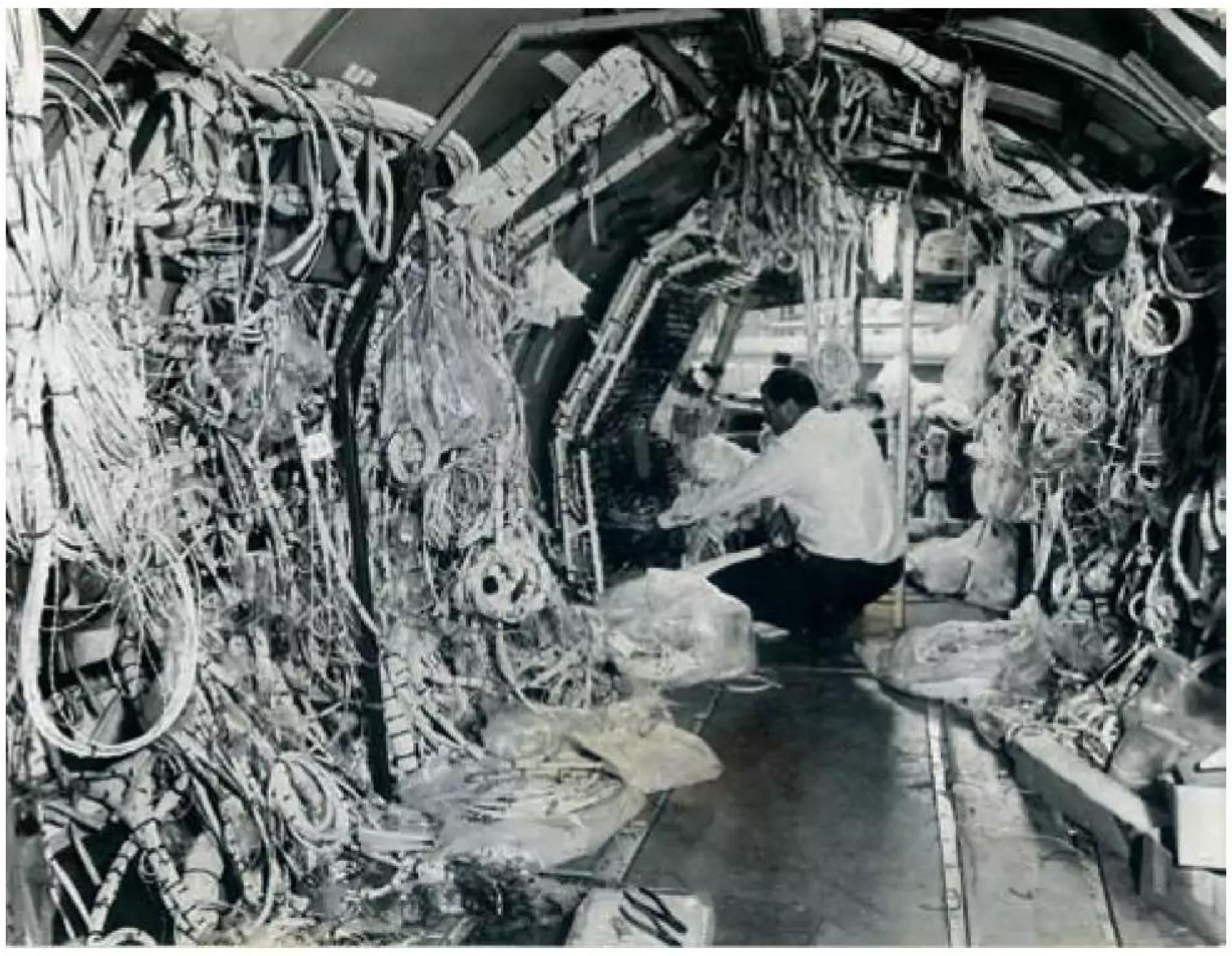
Part of the fuselage of the first prototype seen in the jigs. This section was scheduled for completion in March 1966.



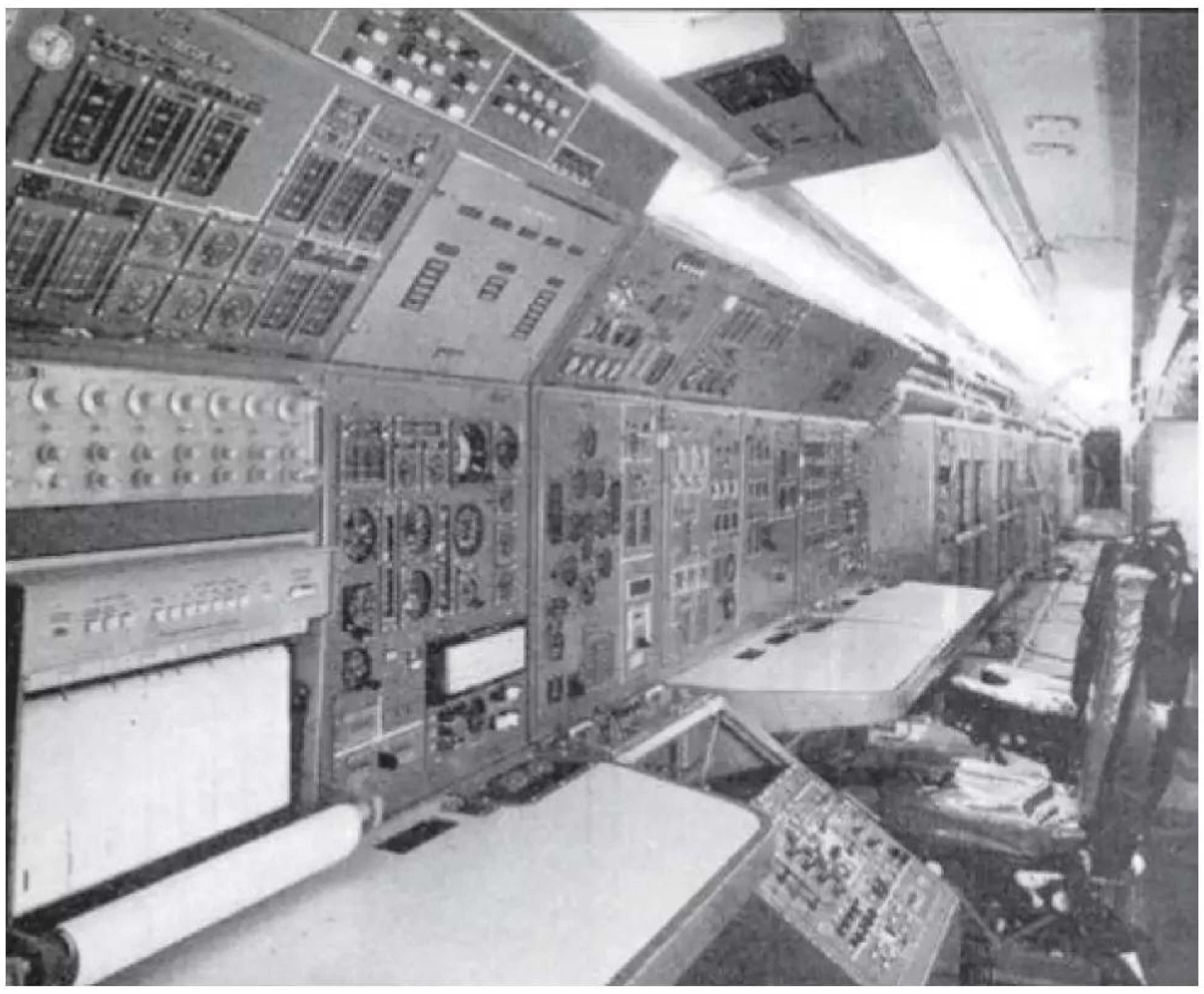
Two major components for the first Concorde prototype pictured in the aircraft assembly hall at BAC Filton. The fin, made at Weybridge, is mated with the rear fuselage which was built at Preston. *Phil Butler*



Prototype 001 had reached this stage of build by 31 August 1966.



Cables and wiring being installed inside the first Concorde.



Inside the cabin of 001 in 1969. Little in the way of passenger seating, but plenty of test equipment. *JC Carbonel*

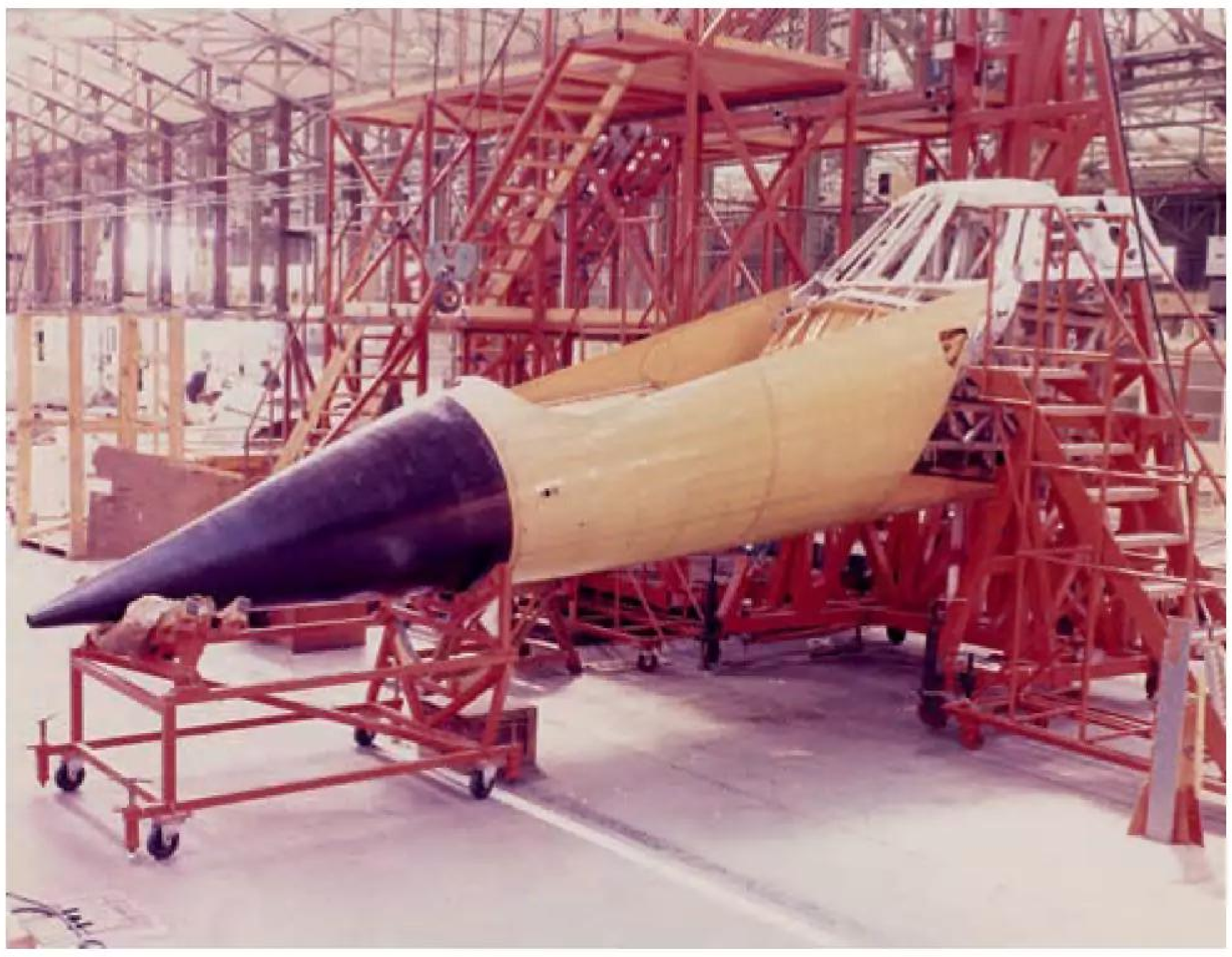
There had been a continuing process of runway improvements which, by and large, had enabled the new demands to be met but occasionally, for example when the Boeing 707 entered airline service, it had been necessary to embark on a major programme of runway improvements worldwide. Throughout Concorde's design and development process it had been the aim to ensure that the runway length and strength requirements would be compatible with the runways being used for the operation of large subsonic jet transport aircraft at the time when the SST entered airline service in 1971.

However, by 1967 it was clear that Concorde would almost certainly present runway strength demands somewhat higher than those of most existing transport aircraft.

In fact an unfavourable evolution of the weight of Concord during 1966 had led to the Concorde Directing Committee (CDC) refusing to approve the definition for the

On 3 December 1967 001 was moved from the Toulouse Blagnac workshops, across Blagnac aerodrome as seen here, to Sud's St Martin plant. *JC Carbonel*

Prototype 002 in assembly at Filton.



The part-complete nose of 002. *BAE SYSTEMS Heritage, Farnborough*

001 in the assembly hall in 1967. *JC Carbonel*

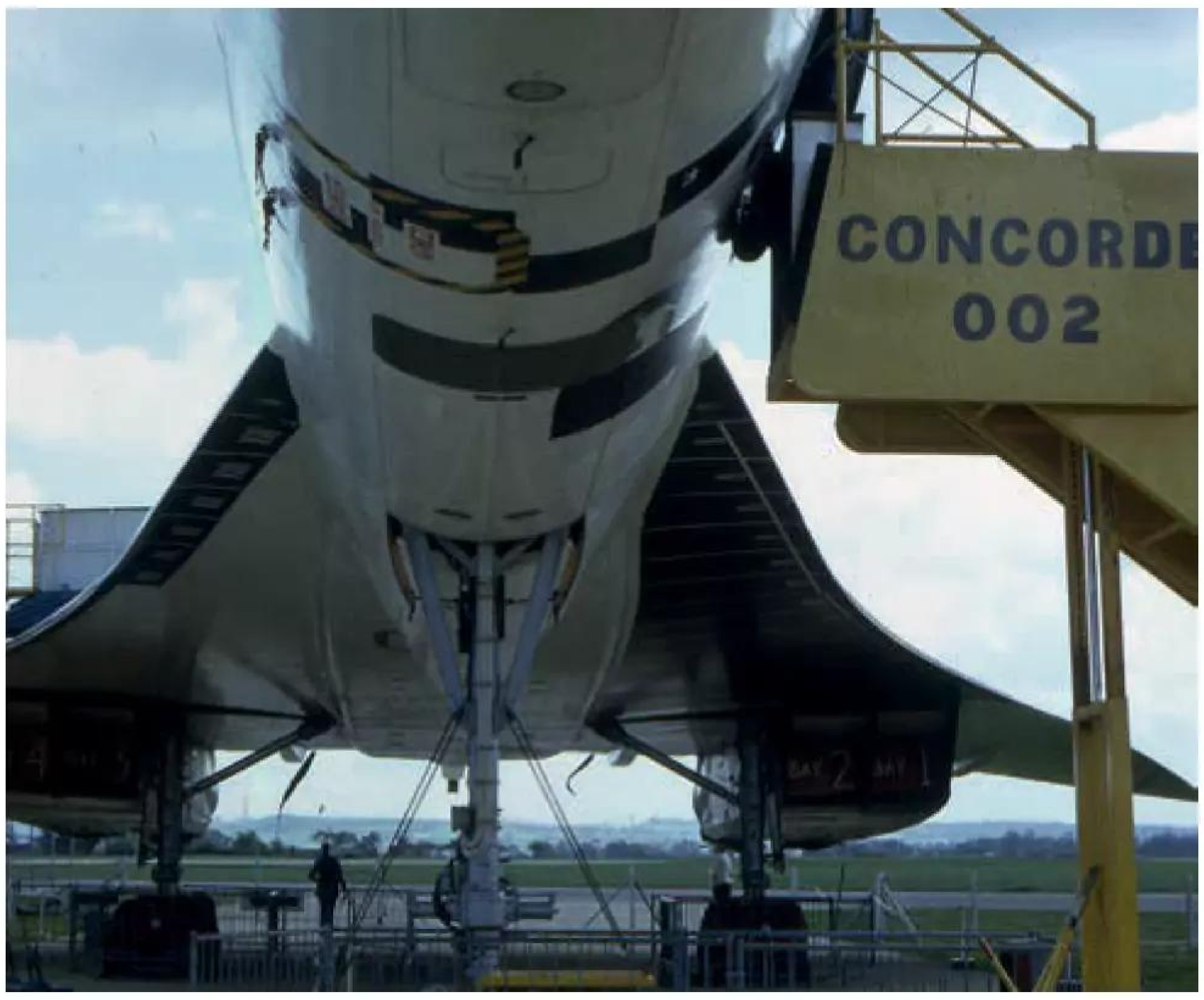
A Concorde airframe undergoes vibration tests at Blagnac in the late 1960s. *JC Carbonel*

pre-production aircraft which had been presented by the aircraft firms in December 1966. The CDC gave the firms until 15 May 1967 to present specific proposals which would allow a recovery of some of the weight increases submitted in 1966. Such was the concern that the CDC had advised the firms that, in the absence of success in this enterprise by this date, it would be obliged to propose to the two Governments that the programme should be halted altogether.

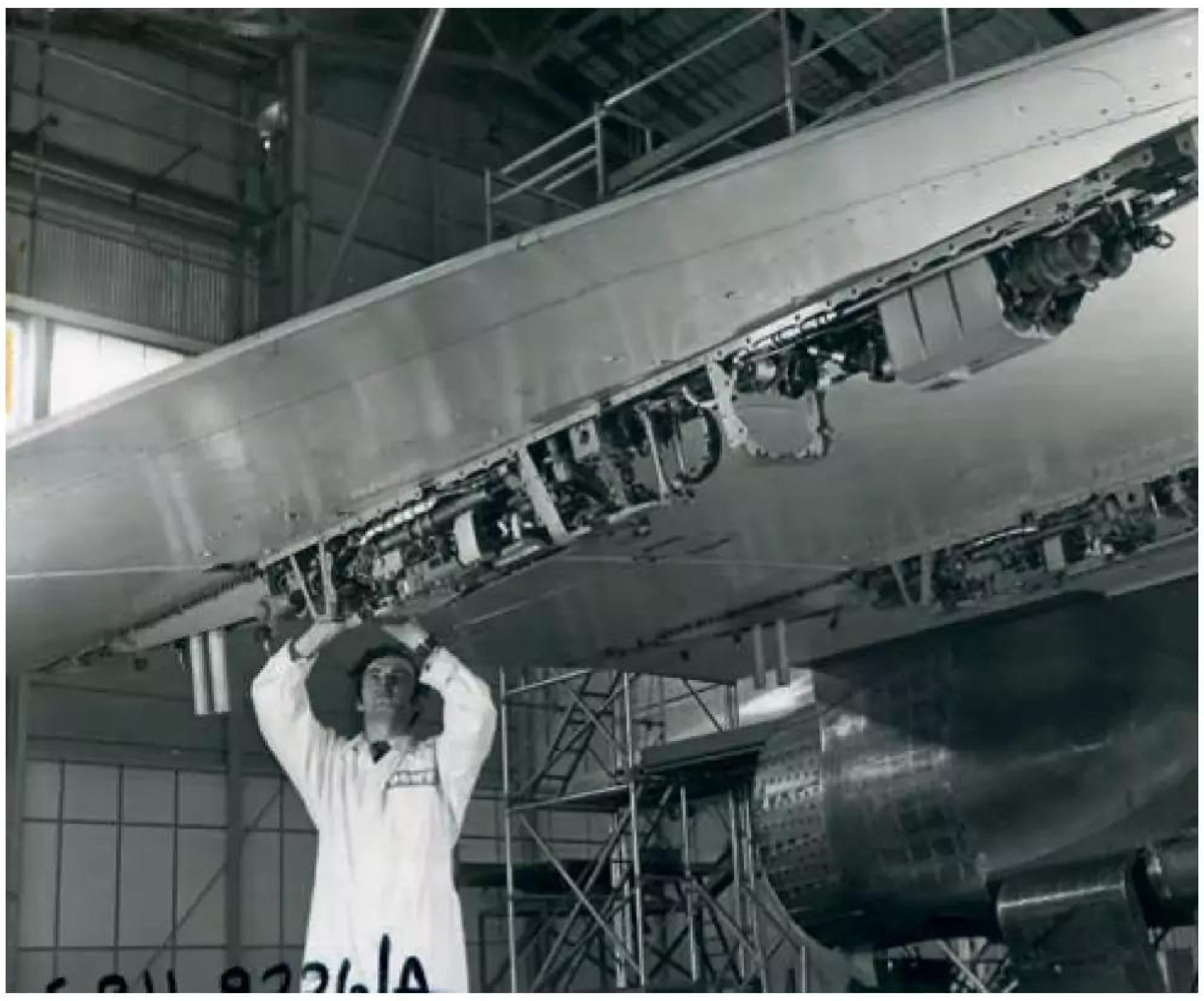
However, with further analysis it seemed unlikely that operating restrictions on Concorde away from the use of weak runways would in themselves be sufficient to affect the sales of the aircraft. Even if improvements in the runway loading position were possible the supersonic airliner could still be operated, although at the expense of increased operating costs. Provided the aircraft was acceptable in all other respects, there was little doubt that the operators would come to terms with the relatively high runway strength requirements. During 1967 five airports were listed as critical in this respect – Toronto, Kano, Lagos, Cocos Island and Brisbane.

UNDERCARRIAGE (JC CARBONEL)

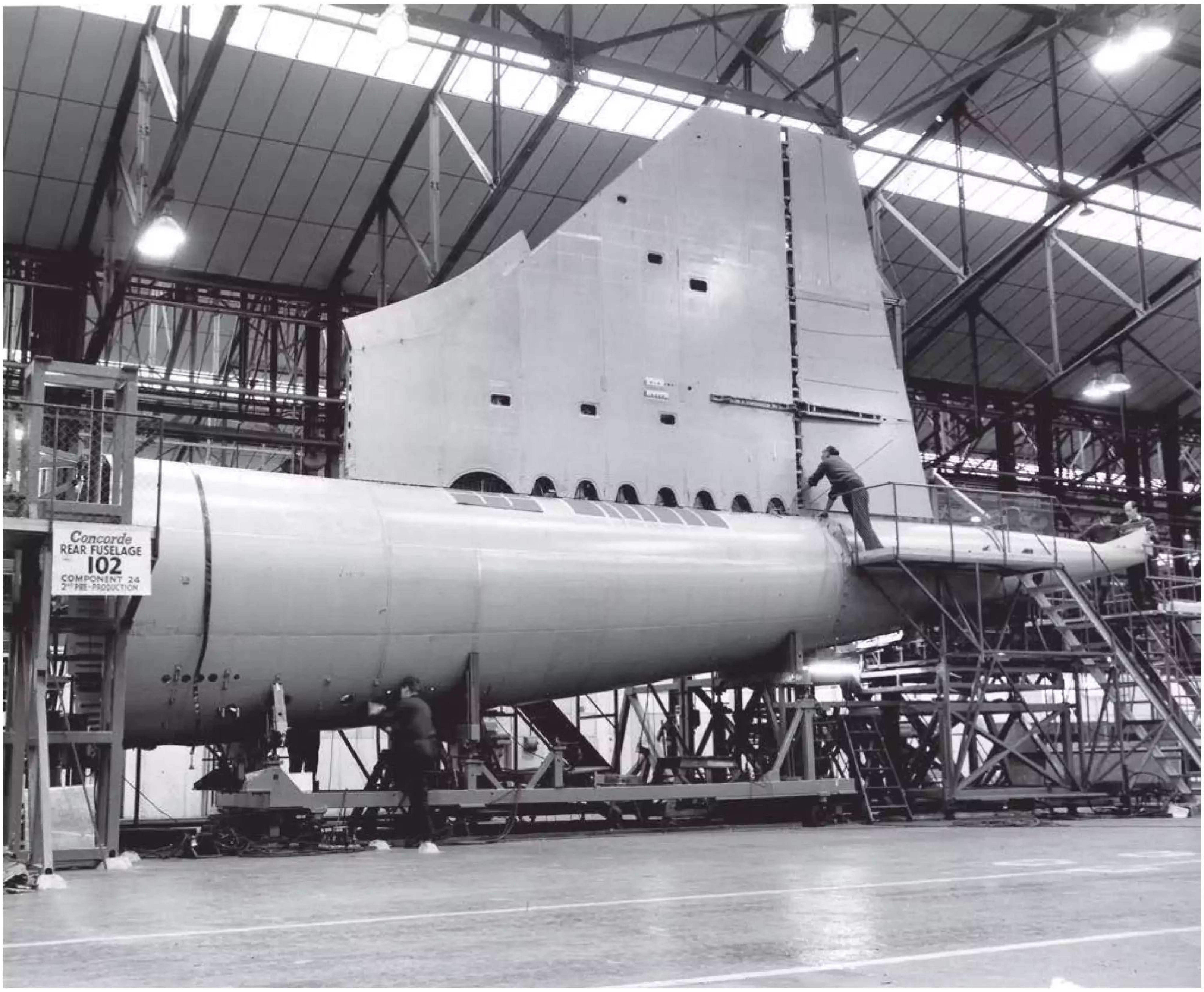
In the original Super Caravelle and BAC 223 designs the landing gear had relatively long legs to help the aircraft


CONCORDE
002

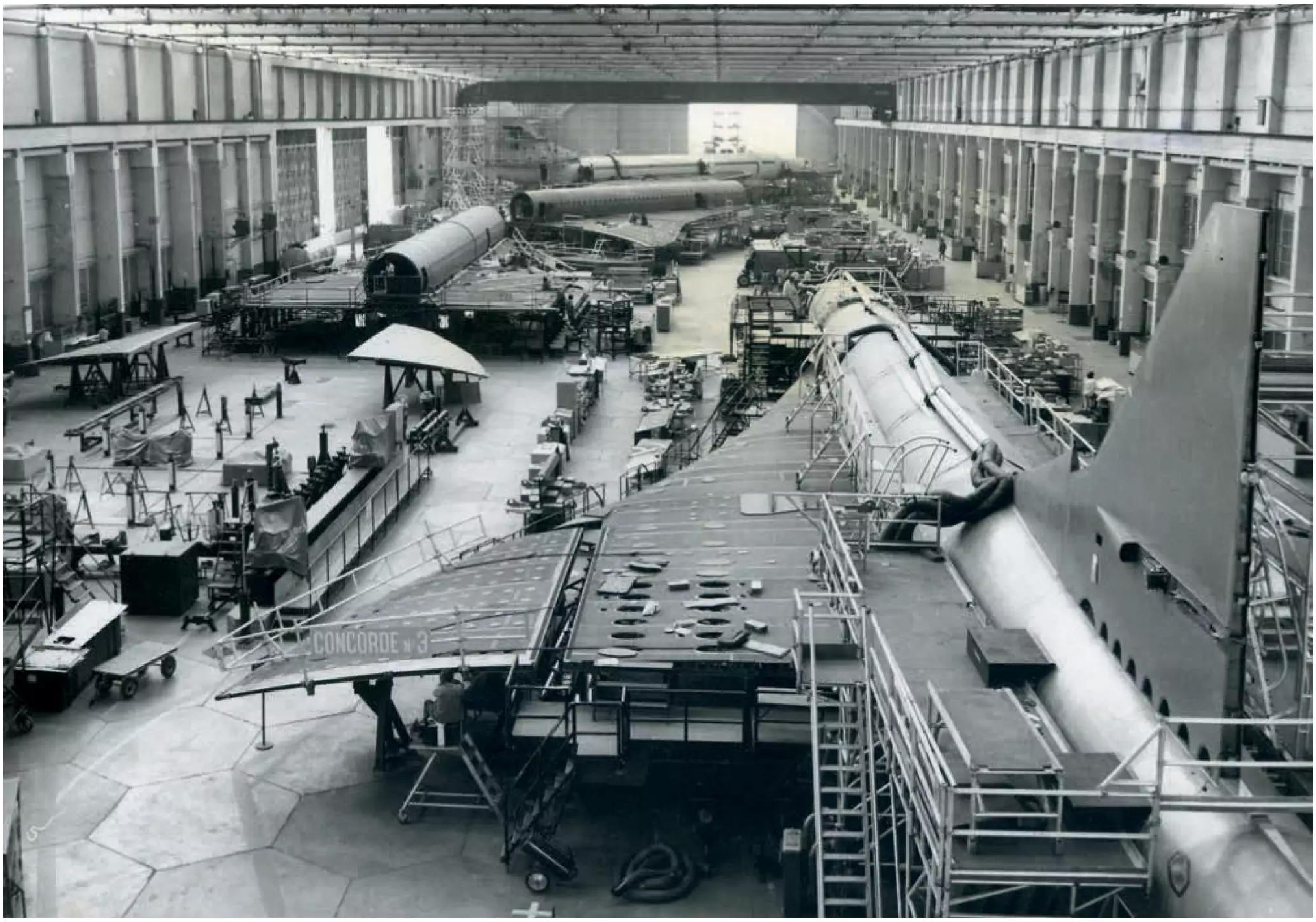
Concorde 002 pictured at an airshow in 1977. Note the numbered covers inside the engine intakes.



Boulton Paul won the contract to supply the Concorde flying controls. This picture was taken in February 1970.


Concorde
REAR FUSELAGE
102
COMPONENT 24
2nd PRE-PRODUCTION

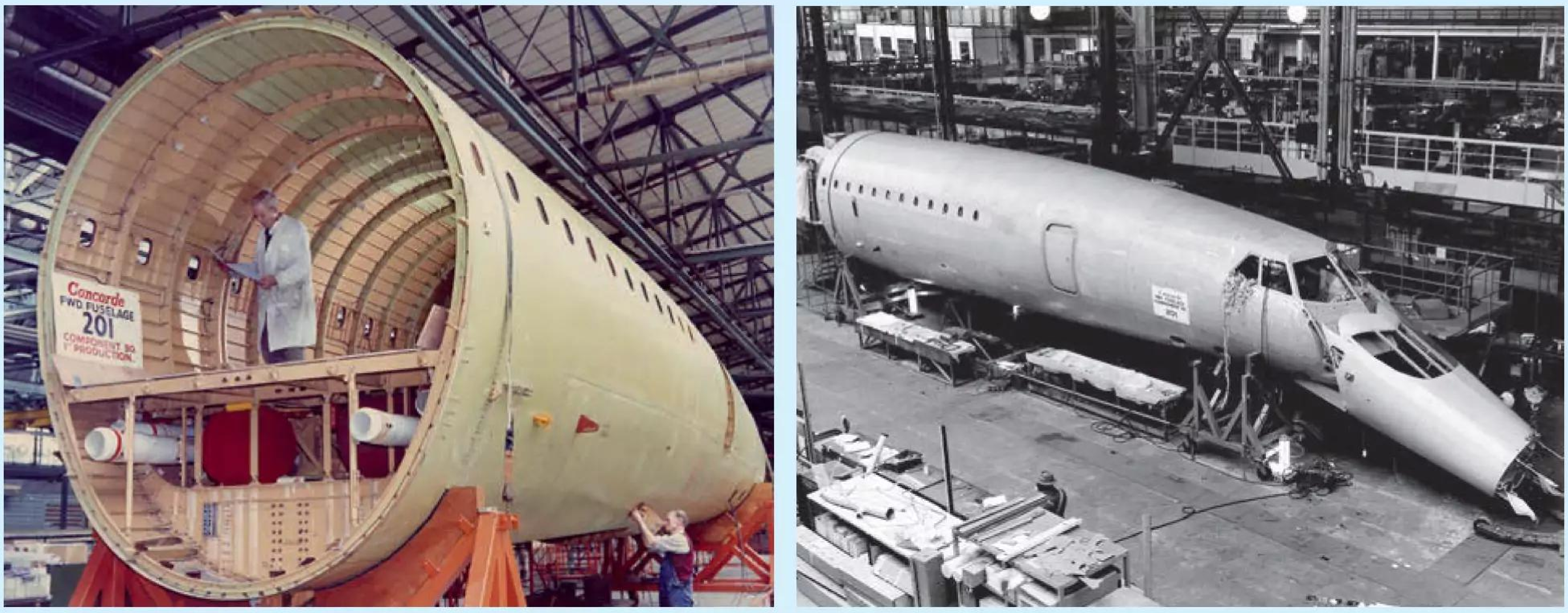
View showing the rear fuselage assembly of pre-production Concorde 102 (F-WTSA) with its tail section, fin and rudder under construction. *BAE SYSTEMS Heritage, Farnborough*



Concordes under construction, with 'Concorde No. 3' in the foreground. *BAE SYSTEMS Heritage, Farnborough*

achieve the high angle of attack required during take-off and landing. This was carried through to the Concorde and two different French companies were allocated the landing gear development work – Hispano-Suiza for the main undercarriage and Messier for the front leg.

Concorde's angle of attack at rotation was about 18° but prior to rotation, and unlike the situation with a normal aircraft wing, here the slender delta would generate almost no lift at all. In addition the airspeed at rotation was 199 knots (369km/h) and this high figure, coupled with the



Views showing the forward fuselage section of the first production Concorde (201, F-WTSB) in manufacture. *BAE SYSTEMS Heritage, Farnborough*

The forward sections of Air France and British Airways Concordes 201, 202, 203, 204, 205 and 206 during production. *BAE SYSTEMS Heritage, Farnborough*

near absence of lift, multiplied the stresses imposed on the main undercarriage in such a way that a redesign would subsequently be required. This high angle at rotation also raised the issue of the end fuselage striking the ground and so a small retractable 'skid' was fitted to the prototypes beneath the end fuselage to prevent such an occurrence and protect the airframe; production machines had a set of small wheels.

It was Messier who supplied the retractable rear skid and this company had also designed the landing gear for the Dassault Mirage IV bomber in titanium, so it had prior experience working with this metal. This was important because of the spindly nature of the Concorde undercarriage as a whole (but notably the forward leg), and the heavy loads it had to absorb, which meant that the use of new high-strength materials like titanium was a requisite.

However, the size of the leg did present a problem to Messier because at one point the company was unable to find a source of forged titanium ingots that were large enough from which to machine the front leg component! The nose gear had a length of over 13ft 2.5in (4.03m) and the shock absorbing stroke was 19.68in (500mm). Even weather was taken into consideration during the development process and the front gear was designed to operate from -60°C to +140°C.

Hispano-Suiza at Colombies in southern France had been involved (as an observer) in the design of the Super Caravelle gear since 1960, so it was no surprise that this company was selected to produce the Concorde main landing gear. This too

A selection of pictures showing the production assembly line in the 1970s.

Part-assembled production Concorde.

was designed to operate under severe conditions. The large height (11ft 6in/3.50m) necessitated the use of a high tensile strength steel, and the chosen alloy was called 35NCD16.

The weight requirement on the undercarriage was imposed by the aircraft manufacturer but the use of high tensile steel in such an application was not well understood at this time and it required new manufacturing processes to be developed. Their height also meant that the legs had to be shortened telescopically for stowage between the nacelles and the fuselage during flight, and the undercarriage deployment and retraction sequences had to be quick.

In 1971 the aircraft landing gear activities of both companies were merged into a new entity called Messier-Hispano, and for production Concordes Messier-Hispano would improve the undercarriage over what had been fitted on the two prototypes. The nose gear was reduced slightly to 12ft 3in (3.73m) while the main gear was extended to 13ft 8in (4.164m). Each of the four wheels on a main bogie had Dunlop disc brakes and there was a SNECMA (Hispano) SPAD (Système Perfectionné Anti-Dérapage or Brake System Control Unit) anti-skid braking control unit. In fact the Dunlop disc brakes were the first carbon-based brakes to be used on an airliner and they saved 1,200lb (544kg) in weight compared to the equivalent brakes having been made in steel.

The resulting SPAD system was first tested on the prototype during towed ground runs made in December 1967. This was followed by tests with the turbojets operating in the spring and summer of 1968, with a final check to follow in February 1969.

The first flights of Prototype 001 did not reveal any problem with the landing gear; on the contrary, the test pilots were particularly satisfied with this fitting. However, shock dampers were blamed for some rough passages experienced over runways that were "known to be bad", for example those at Orly airport. ◆

British airwa
AIR FRANCE

Concordes in Air France and British Airways markings. *BAE SYSTEMS Heritage, Farnborough*

Sonic Booms

7

Concorde takes-off. One can almost feel the noise and vibration in this view as the aircraft blasts away! *BAE SYSTEMS Heritage, Farnborough*

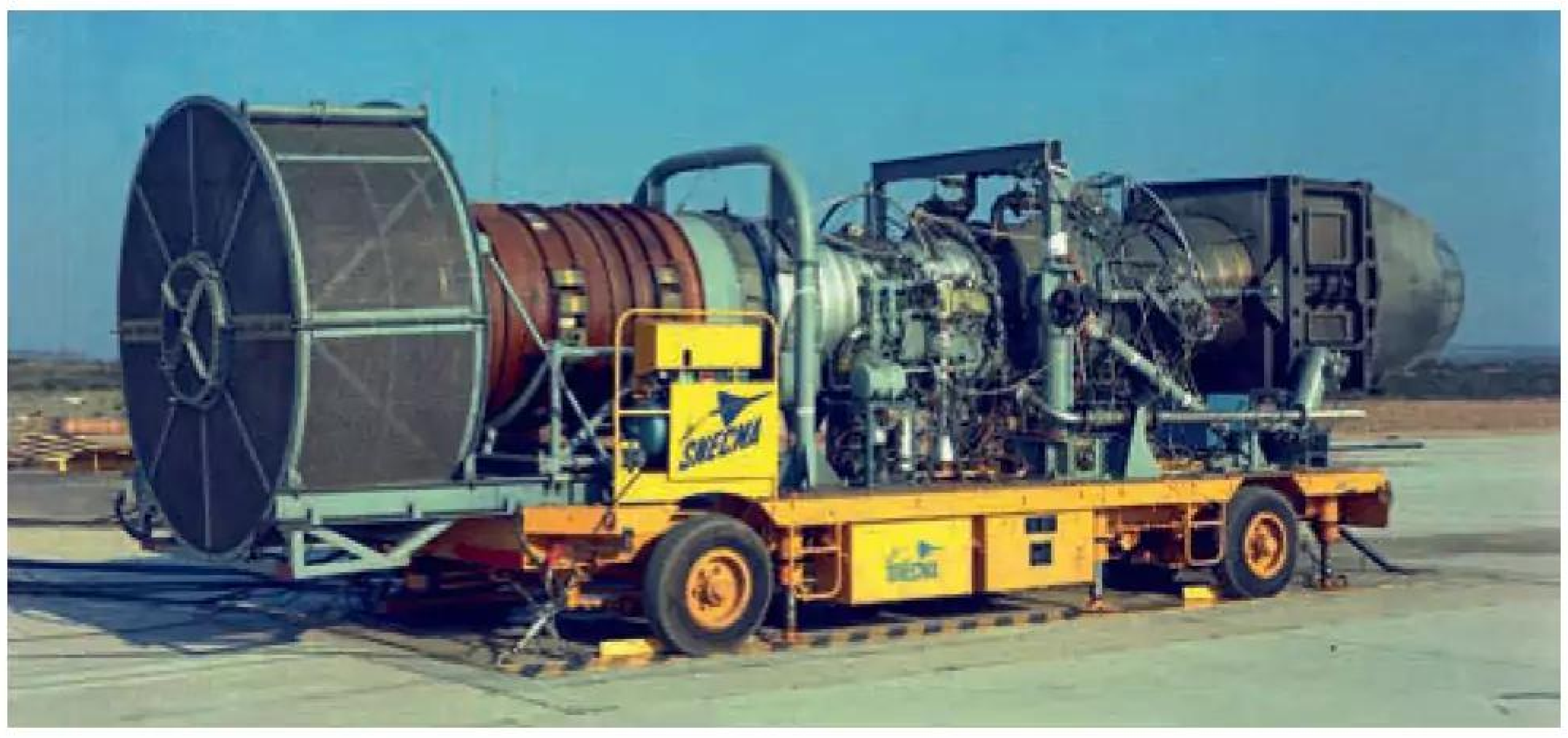
Concorde's potential to make a lot of noise on two fronts (jet engines and sonic booms) proved critical and in the end contributed to the aircraft failing to become a commercial sales success. Noise pollution and the damage which sonic booms might cause were powerful ammunition for what became known as the 'Anti-Concorde' lobby.

The initial objective was to have a supersonic aircraft that produced no more engine noise than current subsonic jets such as the Boeing 707, Douglas DC-8 and Vickers VC.10. However, the next subsonic generation, the Boeing 747, Douglas DC-10 and Lockheed Tristar, would be quieter thanks to their use of high-bypass turbofan engines, the General Electric CF6, Pratt & Whitney JT9D and Rolls-Royce RB.211. So from a social viewpoint, comparisons between the noise made by subsonic and supersonic aeroplanes would be inevitable. Concorde would at least have to be as quiet these big airliners if it was not to bring upon itself considerable annoyance from the communities who lived in the vicinity of the airports from which it operated, and in the process gain a reputation of being 'anti-social'.

By 1964 aircraft noise nuisance had become an important issue, particularly near busy airports such as Heathrow and New York's J F Kennedy (Idlewild). For Concorde, at worst, to be no noisier than current subsonic jet airliners would mean: a) lateral noise at a point 1,000ft (305m) to the side must not exceed 115 PNdB (perceived noise decibels) when the aircraft was on the ground and 120 PNdB once it had become airborne; b) flyover noise at a point under the take-off path 4 miles (6.4km) from the start of its roll must

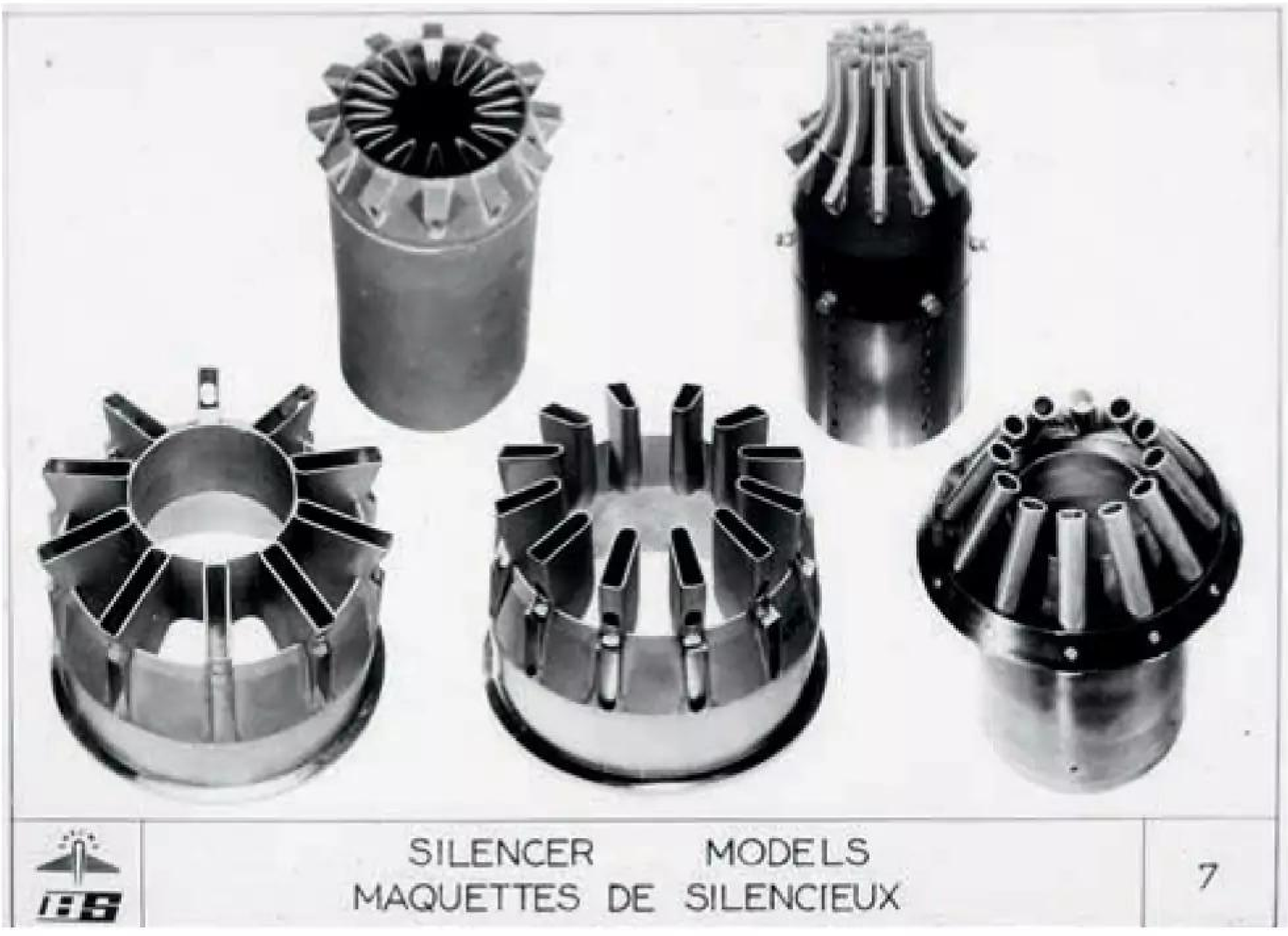
The British prototype Concorde G-BSST. *BAE SYSTEMS Heritage, Farnborough*

One of Concorde's biggest weaknesses was always going to be engine noise around an airport. This picture shows production British Airways Concorde G-BOAE departing in reheat. *BAE SYSTEMS Heritage, Farnborough*



An Olympus engine pictured on the RM-3 test bed at Istres during the mid-1960s. *Espace Patrimoine Safran*

Aerial view of the Istres RM-3 test rig which was used for full-scale open air Olympus 593 testing. This was a sufficiently remote location to avoid troubling too many neighbours. *Espace Patrimoine Safran*



Models of nozzle silencers tested by SNECMA in its quest for lower noise emissions from Concorde's engines. *Espace Patrimoine Safran*

not exceed 110 PNdB during the day and 102 PNdB at night; c) landing noise at a point under the approach path, 2 miles (3.2km) from the threshold, must not exceed 110 PNdB; d) noise from engine-testing on the ground must not exceed 115 PNdB at a distance of 300ft (91m).

The science of acoustics, especially relating to noise nuisance, was and is very complex and designing an SST capable of operating at noise levels comparable with those of contemporary subsonic airliners presented formidable problems. Indeed, the engine thrust and efficiency requirements for a supersonic airliner seemed completely at odds with those for an engine offering substantial reductions in noise.

A supersonic jet engine needed to have a high ratio of thrust to frontal area and a high velocity jet efflux, but the major portion of the noise it generated came from the shearing effect of this exhaust against the static air to the rear of an aircraft, in other words the shear between the exhaust gases and the surrounding atmosphere. And this would increase as the jet exhaust stream velocity was further increased.

Reducing the jet velocity would cut down the noise, but to maintain a specific level of thrust would then normally involve an increase in the engine's frontal area, and that would impose an unacceptable drag penalty for high-speed aeroplanes like Concorde. Conventional fixed silencing systems were heavy inflicted a loss of thrust over an entire flight. Something better was needed and the Concorde design teams concentrated on trying to break down the sharp boundary between the moving exhaust and the static air and on trying to increase the quantity of air passing through the engine itself.

SNECMA was responsible for the design of the retractable silencer and started from scratch. Research into engine noise reduction began in 1962 with an open air test rig called the '32ER' at the firm's main establishment at Villaroche. Later Bristol Engines contributed the use of its anechoic chamber, another anechoic chamber was used at the Centre d'Essais des Propulseurs (CEP) in Saclay south of Paris, and another open air rig was set up at CEV Istres near Marseilles.

The use of this latter location, on a large moor well away from any populated area, permitted the testing of a full-size Olympus for more than 200 hours with running in both 'approach' and 'fly-over' conditions. It had been realised that at a cruising height of 54,000ft (16,460m) and at Mach 2.2 the pressure at the engine intakes would be quite similar to sea level atmospheric pressure, so by heating the air in front of the intake up to 150°C it was possible to simulate these cruise conditions on the ground. Initially SNECMA used a test rig previously used for Atar engines and which in 1964 was modified to accommodate an Olympus. CEP also modified one of its pressure chambers to take an Olympus with its SNECMA-designed rear section.

Tests were also carried out on full size aircraft, involving ten self-contained remote-controlled sets of measuring equipment designed by ONERA. Tests on models were made to define the impact of engine positions relative to the wing and fuselage. In all 250 different silencer designs were tested in scale model form, including corrugated silencers mounted on the primary nozzle, fluid injection silencers (using either air or water), lobe silencers, blade silencers and spade silencers.

In the end, after full scale testing at Istres, a retractable lobe silencer (known as the tilting bells arrangement) was introduced to help deal with the problem of the boundary between the moving exhaust and the static air. This was the original system used on the prototype Concordes and it had a series of retractable lobes in the divergent secondary exhaust nozzle. These could be extended into the gas flow which would then help to break up the hot core gases and suck in cold ambient air to accelerate the mixing process. In all 2,000 cycles of operation were completed either on the ground or in flight to ensure that the lobe retraction mechanisms would operate correctly. The lobes themselves were made in Niobium-base refractory alloy, but they proved disappointing.

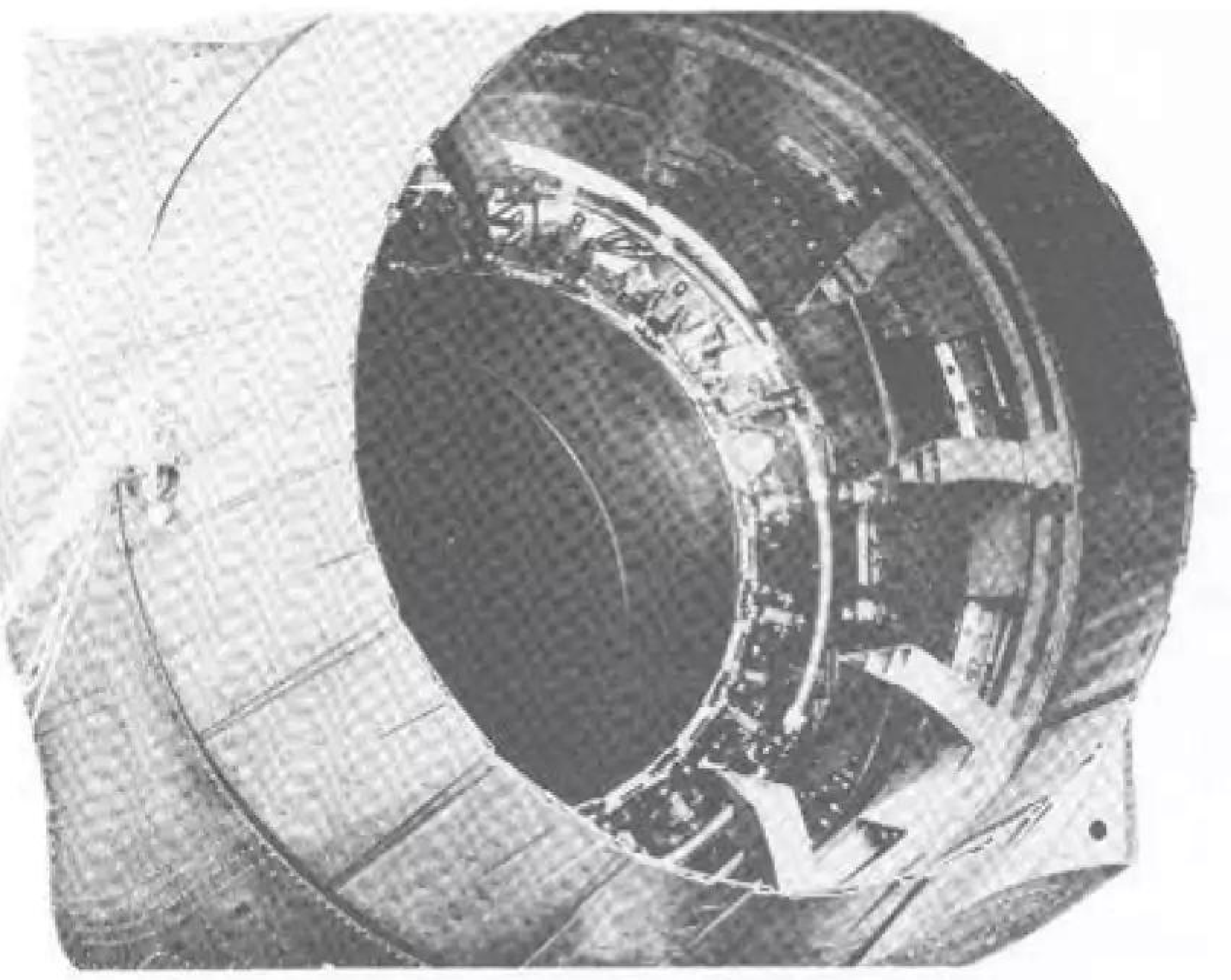
In 1972, long after Concorde's first flight, a joint-nation 'Noise Panel' was established with expert acousticians from both the UK and France. To go with the bench tests already mentioned this body sponsored full-size tests using prototypes 001 and 002, and these tests revealed an underestimation of potential noise levels previously offered by ground experiments and by calculation.

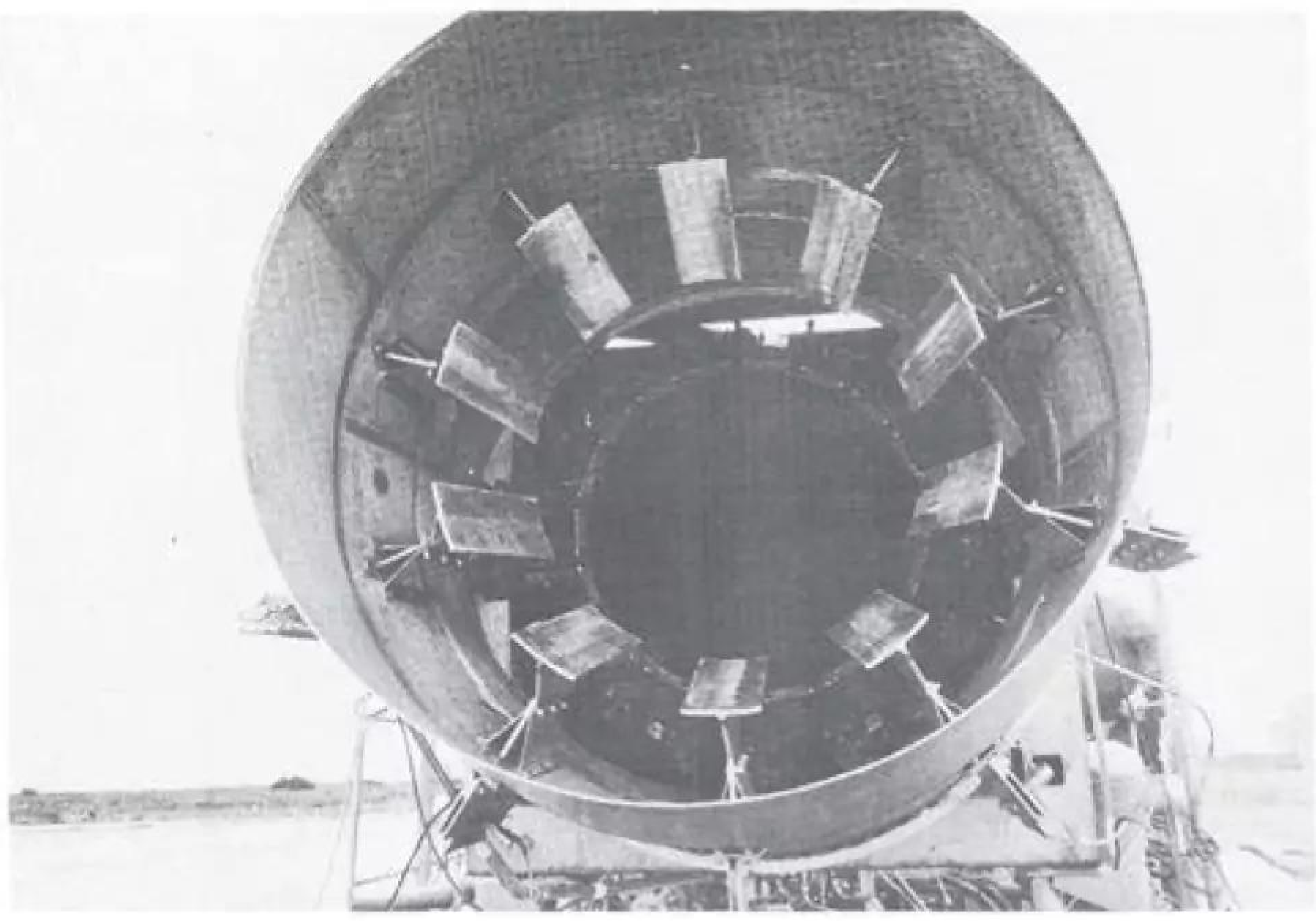
An improved version of the retractable silencing system followed and was known as the 'spade' or 'shovel' silencer since, although operating on similar principles to the 'lobe' system, it used a set of retractable spade-like scoops. These were lowered into the jet stream to break up the efflux by diverting some of the exhaust gas into the annular space between the primary and secondary nozzles, and thus 'corrugate' the boundary between the jet gases and the outside air. Most importantly, since this system was retractable it only had to be in use during the take-off and landing phases and that meant the 'spade' silencer would not affect the aircraft's cruise efficiency because it would be retracted when engine silencing was not required.

However, the 'spade' system gave poor results and was not installed on production aircraft. It was succeeded by a 'bucket' system which introduced a pair of shell doors positioned at the rear of the engine jet pipe. At low speeds these would mix the static air and engine efflux thereby breaking up the shear boundary that produced the extreme noise. And these were the fittings which also doubled as thrust reversers for landing by shutting off the jet pipe and deflecting the exhaust forward, while in supersonic flight they formed a divergent exit nozzle. This versatile idea proved to be far more successful and was adopted for production Concordes.

The second approach to reducing noise – increasing the quantity of air passing through the engine – would produce the same thrust but at the same time reduce exhaust velocity. The solution involved the control (by computer) of the relative speeds of two engine shafts, which in effect meant that the engine was able to 'change gear'. This system could only run once Concorde was in flight and moving at a high enough forward speed to ensure that the intakes could

Concorde 102 F-WTSA was fourth example to be manufactured, and the second pre-production aeroplane. This picture taken on the taxi way at Toulouse shows how large the engine nacelles were compared to the airframe as a whole. *BAE SYSTEMS Heritage, Farnborough*





'Lobe silencers' were tested first on Concorde but were not considered efficient enough. *Espace Patrimoine Safran* take in sufficient air – if they could not then the engine might experience a surge.

The exhaust system eventually developed by SNECMA would help cut the noise generated to a figure approaching that of earlier subsonic jets. On top of this, Concorde's much better climb-out performance ensured that most noise-critical areas were overflown at a greater height. The first noise measurements to be made around Concorde prototype 001 (during engine ground running tests) took place at Toulouse in February 1968 before its first flight. And measurements of the in-flight noise of the Olympus engine installed in the Vulcan Flying Test Bed were made at Filton on 15 February 1968.

THE SONIC BOOM

The familiar noise which most people heard from jet aircraft in the 1960s was derived from the engines and was a real nuisance only in and around airports, but with sonic bangs the reverse applied. Here, for a period following the take-off and again before landing the speed of the SST would be too low to cause a bang – it was expected to accelerate to supersonic speeds at approximately 80 miles (130km) from take-off and then to become subsonic before touchdown at approximately 80 miles (130km) from its destination. But when the aircraft reached supersonic speed it started to produce a bang or boom and would continue to do so for as long as it was flying supersonically.

One of the problems of the sonic bang, even today, is that it can be sudden and startling to people on the ground. The bang would thus sweep across that part of the earth's surface over which the aircraft was flying and the size, weight and geometry of the aircraft, and the height at which it was intending to operate, were the main design features to have any major effect on the intensity of the bang (the prevailing weather conditions, mainly in the lower atmosphere, could also have an effect).

It was considered that unless speeds were restricted when flying below altitudes of about 35,000ft (10,670m), the passage of the aircraft would spread a train of annoyance in its wake. The supersonic airliner would, therefore, have to climb subsonically to around this height before accelerating to its cruising condition at between 60,000ft and 70,000ft (18,230m and 21,335m) altitude; conversely, before descending to the lower altitude it must decelerate to subsonic speed. Thus the time during which the aircraft was flying at its design cruise speed would be limited and the higher the cruise speed then the longer the time required to accelerate and decelerate. So the advantages of the supersonic transport (in terms of block time) would diminish rapidly as the trip length was decreased. This meant that the supersonic aircraft was essentially a long range machine and offered little advantage over short distances.

A Government paper from the early 1960s added that "if the aircraft is not allowed to fly at supersonic speeds for any overland portion of its flight path, or if a more circuitous flight path is stipulated so as to avoid populated areas, then flight times and operating costs will be increase! The London-New York route presents the least difficulty because most of the flight path would be over the sea, but even on this route it is worth noting that flying 80 miles (130km) in a westerly direction from London Airport would bring an aircraft over Bristol and Bath. Flights over other long distance routes and, in particular, the American coast-to-coast routes, would present serious problems if countries are likely to introduce restrictions on supersonic flying over populated areas."

In 1965 it seemed most likely that Concorde would cruise initially at an altitude of around 50,000ft (15,240m) while its rival, the much heavier Mach 3 American supersonic transport, would most probably cruise at a height in excess of 60,000ft (18,290m). This height difference would mean that the two types would in fact be quite similar in terms of the effects produced by their sonic booms. In truth the problem for UK residents was not the noise likely to be made by Concordes leaving London, but more from those supersonic airliners which were over-flying the country from European airports. Clearly the routing of SST flights was going to be critical. Night time operation of supersonic transport aircraft, if required, was also likely to be less tolerable than daytime operation.

In many countries regulations on the banning of supersonic flights of military aircraft over populated areas had been in existence for many years, or at least these flights had been confined to particular corridors. Belgium, Denmark, Holland and West Germany for example all had different restrictions for military supersonic flight over their countries. RAF pilots were forbidden under the Air Force Act of 1955 to fly their aircraft so as to cause unnecessary nuisance and annoyance, and indeed such an offence was liable to court martial and possible imprisonment. And there was a general rule that no aircraft should exceed sonic speed over Britain below 35,000ft (10,670m), while during the let-down and circuit flying the Mach number had to be below 0.8.

Now, with the expected introduction of commercial supersonic transport aircraft, concerns over the intrusive effects of the sonic boom on the population meant that a number of governments began to consider regulations regarding the flights of commercial supersonic aircraft over land in which booms would be generated. Britain did not want to ban supersonic transport overflights unless some concrete reaction against them was received. Otherwise, by banning the flights of foreign operators, Britain would invite similar bans by other countries across the world, thus hampering not only the operations of Concorde, but hampering the foreign sales of the SST generally.

The sonic bang/boom problem would not go away however. At a meeting on 28 January 1964 Hugh Warren, a member of the RAE Structures Department, explained how over the last year the level of bang calculated for the Concorde had risen, partly owing to a weight increase which had resulted in a reduction of the cruising altitude, and partly owing to more satisfactory calculations.

Now, for a take-off weight of some 300,000lb (136,080kg) at the start of cruise, the estimated bang near the ground in the open, on a standard day with no wind, was about 2lb/ft2 (95.8N/m2); at the end of the cruise this would drop to about 1.5lb/ft2 (71.8N/m2).

It was concluded from present estimates, and the limited information available on public reaction, that the sonic bang from the Concorde would be such that some people would find it unacceptable. It was also true that any other long range supersonic transport aircraft would almost certainly give sonic bangs of the same order of magnitude.

SONIC BOOM EXPERIMENTS – UK

Demonstrations of sonic bangs were held at Aberporth on several occasions between 1961 and 1963. Other research and development flights made deliberately to assess the effects of aircraft flying at supersonic speed over land were carried out during the first half of 1963. These were performed by English Electric Lightning fighters operating from the research establishment at Boscombe Down and were made over the approach to Lyme Bay.

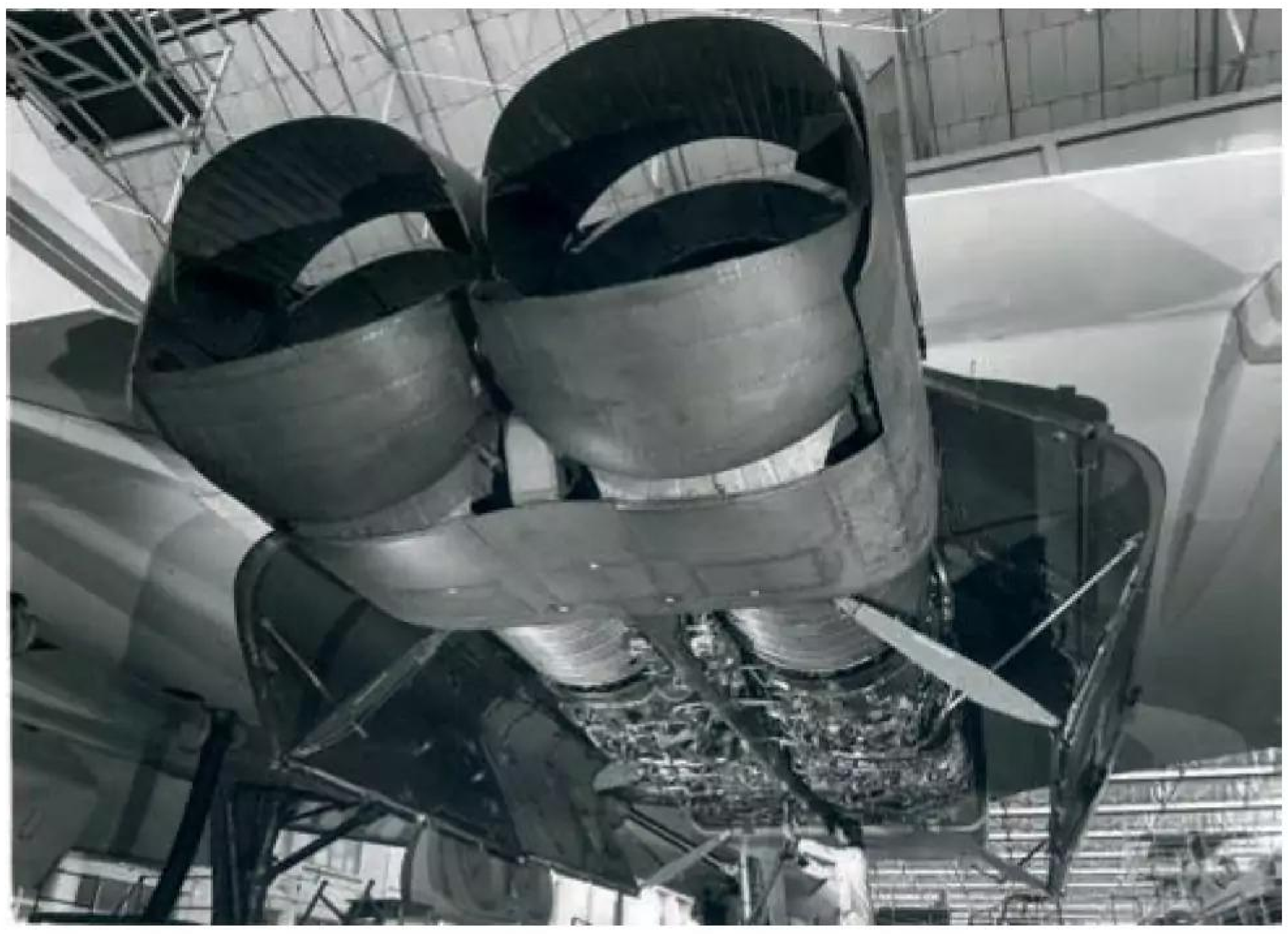
In total 41 overland supersonic runs were completed – 13 from 13 February-28 March and 28 from 16 April-3 May 1963. These flights were classed as being part of the MoA's necessary military aircraft R&D programme and no prior announcement was made to the public in the area. Care was taken to minimise any disturbance as far as possible, but this was normal routine when supersonic R&D flying had to take place over land.

Although these flights were part of the military aircraft development programme, they did provide useful information for the civilian SST development. During the 16 April-3 May period, the National Physical Laboratory (NPL) measured some of the sonic bangs. The peak pressure rise of the 13 bangs recorded ranged from 0.66-2.88lb/ft2 (31.6-137.9N/m2) and this range was greater than had been expected.

In all 146 complaints were received from a population of the order of 75,000 affected by these bangs, 11 claims were investigated, and a total of £92 17s 6d was paid out as compensation in respect of 7 of these claims. A Ministry document added that the number of overland supersonic R&D flights, and the number of associated complaints, made during 1963 and the following three years came to: 1963, 206 flights and 216 complaints; 1964 147 and 37; 1965 96 and 44, 1966 126 and 41.

The next full trial, known as Exercise Westminster, was carried out over RAF Upwood on 21 April 1965. Here three different kinds of noise were assessed, with the first batch coming from Lightnings flying supersonically across the base from the north east. These flights were performed at different altitudes so as to produce double booms of 1-2lb/ft2 (47.9 to 95.8N/m2) in pressure rise against the eardrums of the people listening on the ground.

A Concorde undergoes engine noise testing.



The engine noise problem was reduced through the use of a 'bucket' noise reduction system which introduced a pair of doors positioned at the rear of each engine jet pipe that looked rather like eyelids. These also served as thrust reversers.

Another set involved the detonation of explosives in simulation of sonic bangs with the pressure rises here intended to be near equivalent to those which would be made by Concorde, firstly at its start-of-cruise flight maximum weight (a pressure wave of 2lb/ft2 / 95.8N/m2) and then at its end-of-cruise low weight (1.5lb/ft2 / 71.8N/m2). On top of this came four flyovers made by a subsonic de Havilland Comet 4 jet airliner which used overshoot thrust at a specified height so as to register about 110 PNdB, at the time the permitted daytime maximum noise level for aircraft using London's Heathrow Airport.

During the first part of the programme the human 'victims' stood outside in a sports field, while in the afternoon the sequence was repeated with the listeners inside a solid building with its windows shut. There was some evidence from Exercise Westminster of damage to strained structures, but the bangs did not give rise to any strong objection from the subjects. It was clear that sound buildings should not be damaged by Concorde-type sonic bangs, but strained structures might fail earlier than they should otherwise have done. Overall there was no evidence of adverse effects on the health of human beings or animals.

In July 1967 more supersonic flights were made over selected areas of Southern England so that the general public could once again experience sonic bangs. This programme was carried out under the codename Exercise Summer Sky and the plan had been to open with bangs of mild intensity and then work up to the level of noise to be expected during regular commercial use by Concorde.

These flights were confined to daytime hours and the RAE was asked to participate by measuring the sonic bang pressure waveforms at selected points in each of the three areas. The procedure was for several Lightning aircraft operating from A&AEE Boscombe Down to fly at 43,000ft (13,105m) and Mach 1.4 on pre-determined but publicly unannounced routes. The resulting booms would be heard along a ground path extending some 15 miles (24km) to either side of the mean aircraft track. Again, the idea was to observe public reaction to sonic bangs in order to build up some information of the consequences of overflying parts of the country with supersonic transport aircraft.

Over a period of two and a half weeks a total of 11 bangs were made – two primarily over Dorset, five over the Bristol Channel to Bristol, and four over the Thames Estuary to London. The bangs were apparently kept to a nominal intensity of 1lb/ft2 (47.9N/m2) when near the ground and in the open, which was about half of what might be expected from Concorde. Each bang over Dorset was heard by about a quarter of a million people, those over the Bristol Channel area by about 1.5 million people, and those over the London area by about 11 million people. Of this total of nearly 13 million, about 12,000 complained, 9,600 of the complaints coming from the London area. In all nearly 800 claims for compensation for damage were received and about 500 of these were accepted. After Exercise Summer Sky such flights were for the time being halted.

Studies of the reaction to sonic bangs had also been carried out in France in connection with military overland supersonic flying, which was permitted in France subject to altitude restrictions. In October and November 1965 a sample public opinion survey was carried out in two areas which had experience of sonic bangs from military aircraft. In what was considered an important conclusion, it was found that the dislike of sonic bangs was less among those best informed about them.

British Ministry documents also made reference to some US Federal Aviation Agency tests made in 1964. Here, during the six months over which these tests had been conducted, a total of 1,394 sonic bangs were made on a regular daily basis over Oklahoma City. About 12,000 complaints or enquiries were made (some 2,000 of them repeat calls) from a population of 600,000. Most of the complaints related to fears about the damage to property.

A Ministry of Aviation report prepared for the Government and dated 31 January 1967 summarised the then known effects of sonic bangs. Much more was now known about the effects of bangs from three sources – theoretical studies, from the incidental experience gained from flying military aircraft supersonically, and from tests directed specifically at the problem. It was also known that intensities far greater than those expected from normal operations by SSTs had to be reached before damage definitely attributable to bangs would occur to well constructed buildings. There was also no real evidence that bangs of the intensity expected would be harmful to the health of people or animals. The main reason for anxiety was that people would find the bangs so disturbing and alarming that they would consider them intolerable.

SONIC BOOM EXPERIMENTS – FRANCE (JC CARBONEL)

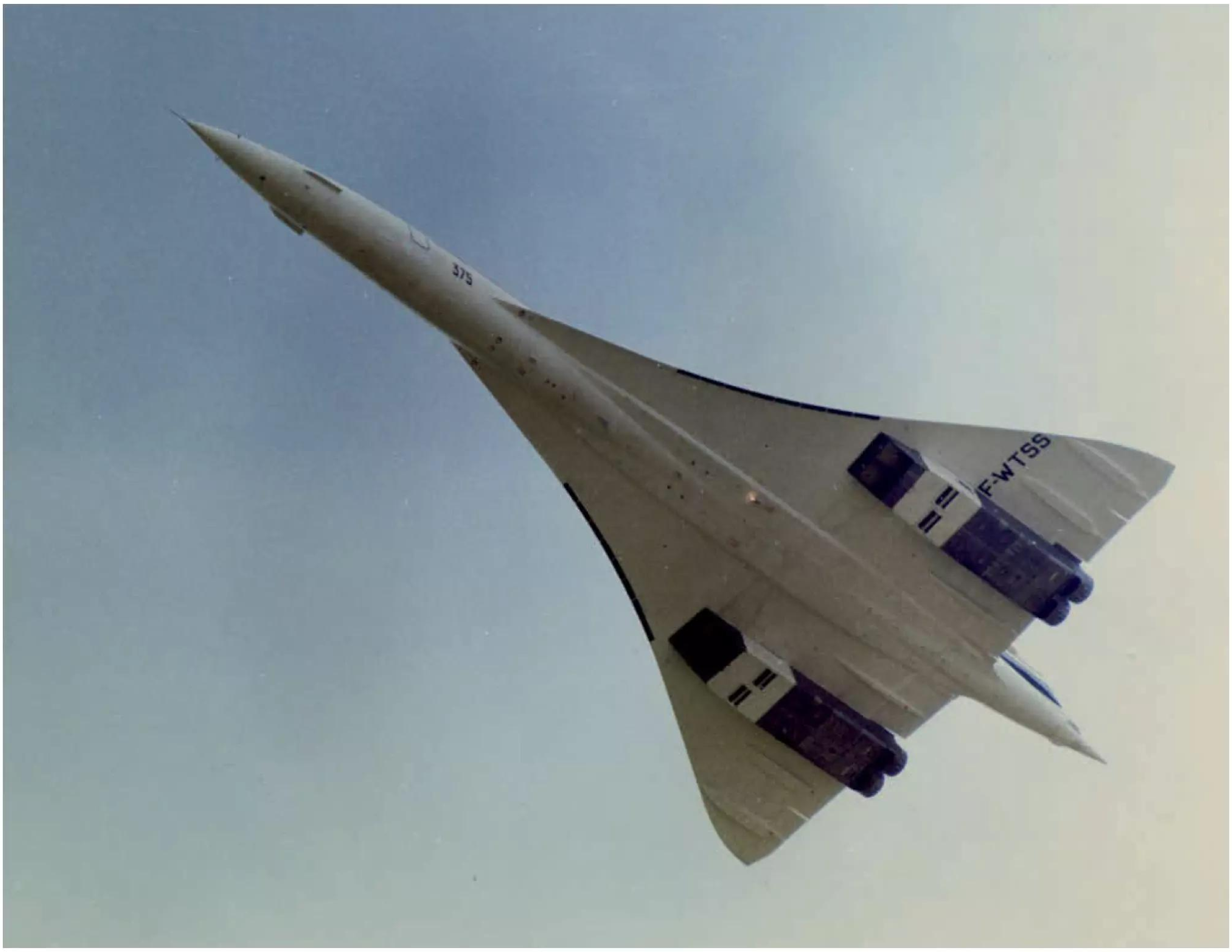
Similar operations were begun in France. While Sud's Super Caravelle was still only a concept, the problems associated with noise (inside the aircraft, at take-off, cruise noise and the sonic boom) had just not been addressed. Even for a vertical take-off version of the Super Caravelle proposed in 1959, which would have been horribly noisy, the brochure did not even include the word 'noise'.

And in its 30 April 1961 Super Caravelle III brochure, Sud showed extraordinary contempt towards the problem because at no stage did this document, consisting as it did of 10 spiral-bound booklets each about 10mm (0.4in) thick, raise the question of noise.

Nord Aviation was slightly better with a three-page 'noise' addendum to the section in the brochure which covered performance. Here at least it recognised that "an aircraft flying at supersonic speed generates a pressure wave on the ground [of an] intensity which could cause damage". It referred to previous studies made by AGARD and by NASA which had involved a B-58 Hustler (AGARD was the Advisory Group for Aerospace Research and Development, a NATO agency in existence between 1952 and 1996).

Nord had proposed a canard configuration aircraft and recognised that "the presence of a large canard surface on the forward section of the fuselage might aggravate the ground noise". The addendum continued by showing (through calculation) that going through the sound barrier above 11,000m (36,090ft) would sound rather innocuous on the ground. This fitted in well with the then current proposed flight plan in which, to limit the noise at ground level, the aircraft would climb at a 15° angle (considered acceptable for the comfort of the passengers) at Mach 0.9 and reduced engine power up to a height of 11,000m (36,090ft). The pilot would then accelerate sharply to pass through the sound barrier at 11,000m (36,090ft) and then continue climbing and accelerating towards its cruise speed.

The Dassault brochure provided many pages and a lot more detail on noise, covering all aspects of the subject. For



Despite its sleek shape Concorde would at maximum cruise speed always produce a powerful shockwave and sonic bang. This beautiful underside image shows the first prototype F-WTSS just after take off. *BAE SYSTEMS Heritage, Farnborough*

At the time of writing the only Lightning identified as having been involved with experimental 'supersonic bang demonstration' flights is pre-production aircraft XG326 in May 1961, when it was based at A&AEE Boscombe Down. This view shows the second English Electric P.1B (prototype) XA853 which was used by A&AEE for extensive trials from 1959 until 1963.

noise inside the fuselage the report stated that, through the use of fibre-glass insulation and the cabin's interior fittings "the soundproofing of the passenger cabin does not present any insurmountable problems. Considering the thickness of the sheet metal required for the structure and the thickness of the thermal protection required for air-conditioning the cabin, it appears that internal fittings similar to the ones used on the [subsonic] Caravelle would insure a satisfactory level of sound proofing".

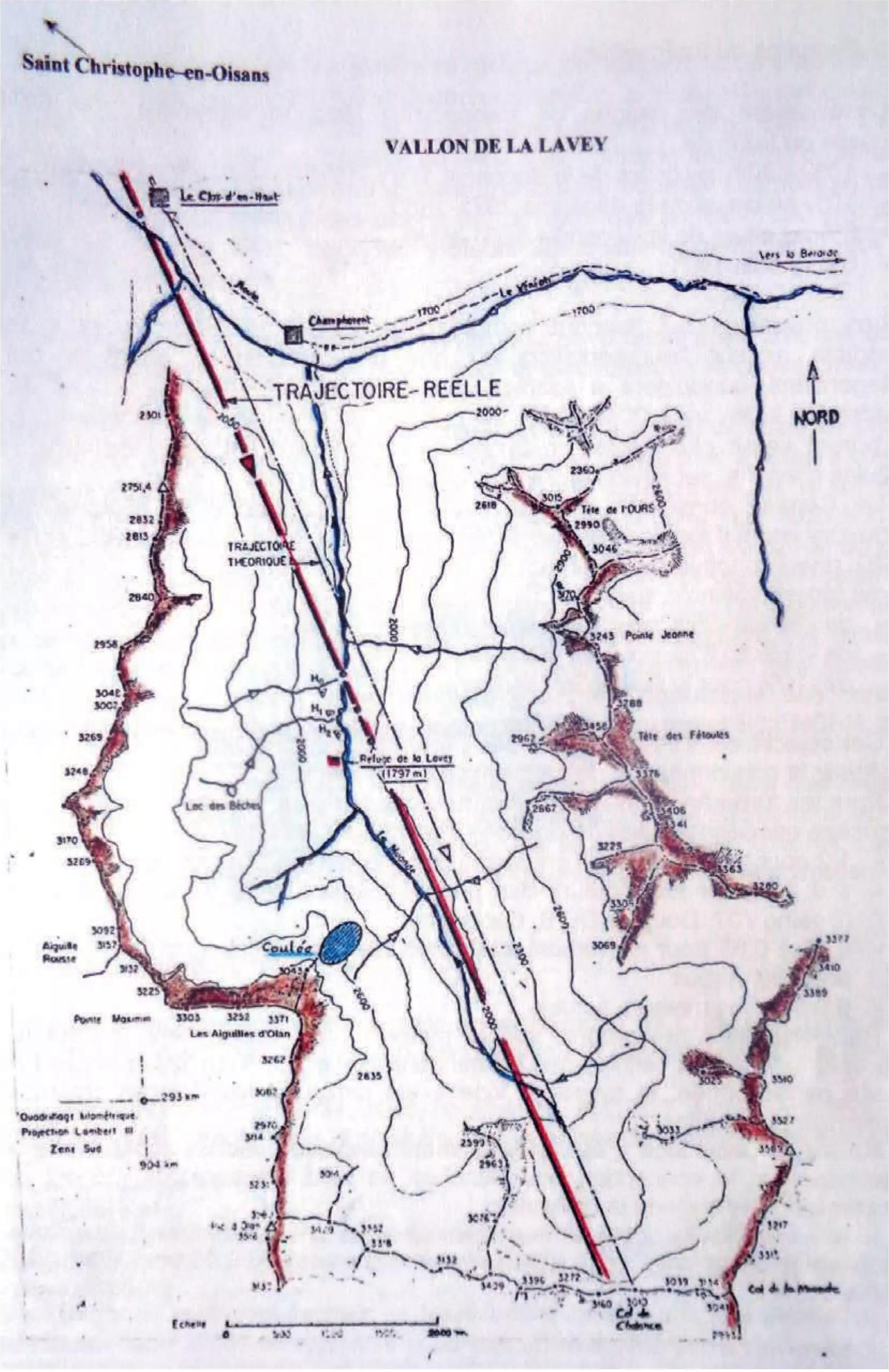
In regard to turbojet noise at take-off, Dassault referred to measurements taken at New York and London airports for the Caravelle, de Havilland Comet IV and Boeing 707 and concluded that, if its own Super Caravelle SST design took off at 65% engine thrust, its four RB.169/2 engines would generate between 108 PNdB and 112 PNdB depending on the speed and altitude of the aircraft (a slightly higher figure than for subsonic types).

Up to this point Dassault was the only French player in the SST saga to worry about the psychological impact of repeated sonic booms on the population, but it declared that it could not make any conclusions because of a lack of data. It did suggest that a sound similar to a "far away thunderclap" (or more mathematically a pressure of 47.88N/m2 [1lb/ft2]) would be the maximum admissible, and that physical damage to buildings was estimated to start at levels of 95.76N/m2 (2lb/ft2). The Dassault document ended by saying that the "sound impression made by the over flight" of an SST would be 40% greater than that of a Mirage IV and it recommended that a programme of testing using one of these bombers should be carried out, which at that time was the largest Mach 2 aircraft available in Europe.

STAé took Dassault's idea on board and a memo dated 19 June 1961 asked about the possibility of using a Mirage IV for such tests. CEV then made plans to use the prototype Mirage IV 001 for tests during September and October 1961. In November 1962 a series of tests called 'Jericho Mirage IV' was undertaken under the auspices of STAé.

That same year SNECMA began research on the attenuation of Concorde engine noise using an open air test rig at Melun-Villaroche. An agreement was reached at this time with Bristol Siddeley Engines that the most promising designs of silencer produced by SNECMA would be assessed at the correct jet temperature in the anechoic (free from echo and reverberations) chamber at Bristol.

Later, the Institut Franco-Allemand de Saint-Cyr started a programme called 'Jericho-Marina' which was carried out in November 1964 using a Mirage III fighter. The name Jericho was then used again to test a theory proposed by scientist Claude Vanner regarding the focalisation of the sonic boom. Through an effect called 'focalisation' Vanner said that at the beginning of the aircraft's acceleration a sound wave could sweep an area about 120km (75 miles) wide with a pressure many times higher than the one generated by cruise flight at Mach 2. In due course 'Operation Jericho-Focalisation' of February 1966 involved the measurement of sonic booms on the ground following overflights by a supersonic aircraft flying straight and at low level. The aircraft was Mirage IIIA No. 03 operating out of Istres and it made what were termed low-level "passages à la tour", i.e. flights in front of an airfield control tower at sufficiently low level for visual observations. This sequence of tests indicated that the sonic boom was not really a nuisance during cruise flight, but it would be a problem during the acceleration phase.


Saint Christophe-en-Oisans
VALLON DE LA LAVEY
Le Clot-d'en-Haut
Vers la Bérarde
Le Vénéon
Champhorent
TRAJECTOIRE-REELLE
NORD
Tête de l'OURS
TRAJECTOIRE THEORIQUE
Pointe Jeanne
Tête des Fétoules
Refuge de la Lavey (1797 m)
Lac des Bèches
La Muande
Coulée
Aiguille Rousse
Pointe Maximin
Les Aiguilles d'Olan
Quadrillage kilométrique Projection Lambert III Zone Sud
Col de Chalence
Col de la Muande
Echelle 0 500 1000 1500 2000 m

Map of the overflight made by a CEV Mirage IIIB over the valley of Lavey in the Alps. Trajectoire réelle = the actual trajectory flown by the Mirage, trajectoire théorique = the planned trajectory. The blue area marked 'coulée' indicates the spot where an avalanche was started by a sonic boom.
CEV via JC Carbonel

Trials also now began using the Mirage IV bomber. From 9 to 24 October 1967, Mirage IV No. 04 performed simulated approaches and departures to and from Orly airport to investigate the insertion of an SST into normal air traffic. But sonic booms were also investigated, notably an overflight of the Island of Jersey at Mach 2 and 15,240m (50,000ft) which generated some complaints.

As a result, new routes were tried for subsequent flights with the intention of keeping booms away from coastal areas but without having to delay the beginning of the supersonic acceleration. These alternative flight paths did not bring any complaints from anyone, but the conclusion was that during the departure flight the 'cut-off Mach', from which point the ground did not receive any boom, had to be reached after the aircraft was over the sea.

In addition, the approach to landing also had to be made at subsonic speeds when the aircraft was above the ground. In May 1969 Mirage IV 04, operating from Istres again, was used for Operation 'Jericho Virage' which measured the effect on the ground of an aircraft following a curved flight path when flying at 11,000m (36,090ft) and at supersonic speed. Istres was also the base for 'Jericho Carton', which took place in about 1972 and involved a Mirage IV and a Mirage IIIB.

A meeting was held between all of the partner manufacturers and research establishments on 23-24 September 1969 to organise a trials programme using Concorde 001. Ingénieur Principal De Maistre of the STAé proposed that the sound/pressure signature of Concorde should be measured at low Mach numbers. Then CEV's J. Renaudie presented a measurement device called the Canibal (Contrôle Automatique du Niveau de Bang Local or Automatic Measurement of Local Boom Level). A contract for a batch of these ground-based sound recorders had been placed on 17 September; they were basic machines and not intended to be positioned and activated by specialists. In fact, it was suggested that the Gendarmerie Nationale should position them and that CEV should keep an eye (or should that be an ear?) on the reaction from the public to booms generated by Concorde 001.

During the first year of test flying by 001 over the south of France, 46 supersonic flights were accumulated and 26 complaints logged, but the Concorde team was quick to add that "no correlation between the flights of Concorde and these complaints has been established". It was acknowledged that over-pressures [generated by the boom of Concorde] were much higher [than usual] "and may be the origin of some of the complaints". The first measurements had been taken on 11 December 1969 during flight 73 when 001 flew at Mach 1.3 above the CEV base at Istres, sound recorders having been installed for the occasion by CEV, Institut de Saint-Louis and RAE Farnborough. The measurements, taken at 45,000ft (13,715mm) and then 37,000ft (11,280m), were stated as being 'quite close' to the theoretical calculations, much to the satisfaction of the acoustic engineers from CEV and RAE. Witnesses on the ground said that the boom felt like "two neatly separated cracks". The external noise at take-off and landing was also measured and BAC's Sound Laboratory reported that the sound levels corresponded to the levels which had been predicted mathematically.

On 9 October 1969 a meeting was held between STAé and CEV at Brétigny and among the subjects on the agenda were the political aspects associated with Concorde's sonic booms. The question was in fact raised as to whether Concorde 001 should participate in the Jericho experiments at all. These trials were regarded as more wide-ranging than just SST research, and Concorde had problems of its own associated with that fact that it was purely a commercial aircraft (for example with FAA certification). In the end, to avoid dissemination of the Concorde noise measurements to the outside world, the Director of CEV I.G. Pommaret made the decision that "Concorde must be dissociated from the Jericho experiments. Boom experiments with Concorde will be planned and carried out in the view of [associated] Concorde [personnel] only and at the most favourable moment".

In March 1971 a Provence-style house was specially built near Istres in readiness for operation 'Jericho-Casbah', an experiment which saw this new building overflown at high and low altitudes by a Mirage III. It was concluded from this trial, and from others made during the normal operation of military aircraft in Bourgogne and Champagne, that "the threshold above which sound structures are damaged is well above the nominal boom level generated by Concorde, but it is not possible to estimate disorders which could appear on badly built or maintained buildings".

May 1971 saw Concorde 001 involved in another operation to estimate the impact of the sonic boom. Named 'Sierra Three-Time' (from 'Survol Super Sonique', Sierra is the phonetic letter S) this was organised by CEV for 001 flights 135, 136 and 137 on 12, 13 and 14 May respectively. It consisted of straight and level flights made at Mach 2 and 15,240m (50,000ft) along a path from Saint-Brieuc to Istres. CEV had Canibal recorders distributed along this route, although the main area of measurement was to be the Crau plain near Istres. Although about ten million people were subjected to the booms this time, no collective 'upheaval or adverse press campaign' resulted (although 26 complaints were logged for broken panes of glass and cracks in walls or ceilings). In fact it appears that the origin of these booms (Concorde) was never identified to the public.

Finally, in 1974, 1976 and again in 1977 the Laboratoire d'Applications Spéciales de la Physique (Special Applications Laboratory) of the Centre d'Etudes Nucleaires de Grenoble (the Grenoble Center for Nuclear Studies) was asked to investigate the potential effects of sonic booms on snow avalanches. Eleven overflights of the Alps in 4 sorties from March-May 1974 by one of CEV's Mirage IIIBs produced two avalanches. No further such incidents resulted from three further flights in December 1976-March 1977.

The view of Concorde that most people would see if they were in a position to hear a sonic boom from the aircraft. *BAE SYSTEMS Heritage, Farnborough*

It was concluded finally that the sonic boom was not a good instigator of avalanches, but by now this had become a moot point since it had been requested by the world's aviation authorities that Concorde should fly supersonically only over seawater.

ANTI-CONCORDE CAMPAIGN

Environmental activist Richard Wiggs founded the Anti-Concorde Project in 1967 to pull together the growing opposition to, and complaints about, the aircraft. He and his colleagues challenged the idea of SSTs and thereby did much to curtail Concorde's commercial prospects.

Noise was the biggest element of concern but other factors such as the possible depletion of the ozone layer in the Earth's atmosphere were also stated.

Some in UK government were dismissive of the militant organisations protesting about aviation, and particularly those groups formed specially to "ban the boom". There was no doubt that some people were guilty of what was termed 'the compulsive neurotic complaint factor', and time and again alarmist stories of the potential effects of radiation on passengers, or the harmful depletion of ozone in the stratosphere, or excessive oil consumption, failed to stand up to scientific enquiry.

This was irrelevant to those who were against Concorde anyway and they exploited the environmental aspect as a weapon with which to attack the airliner regardless of the realities of the situation. At the same time, however, a lot of serious and highly respected and distinguished people backed the Anti-Concorde Campaign because they were genuinely worried about the environmental issues.

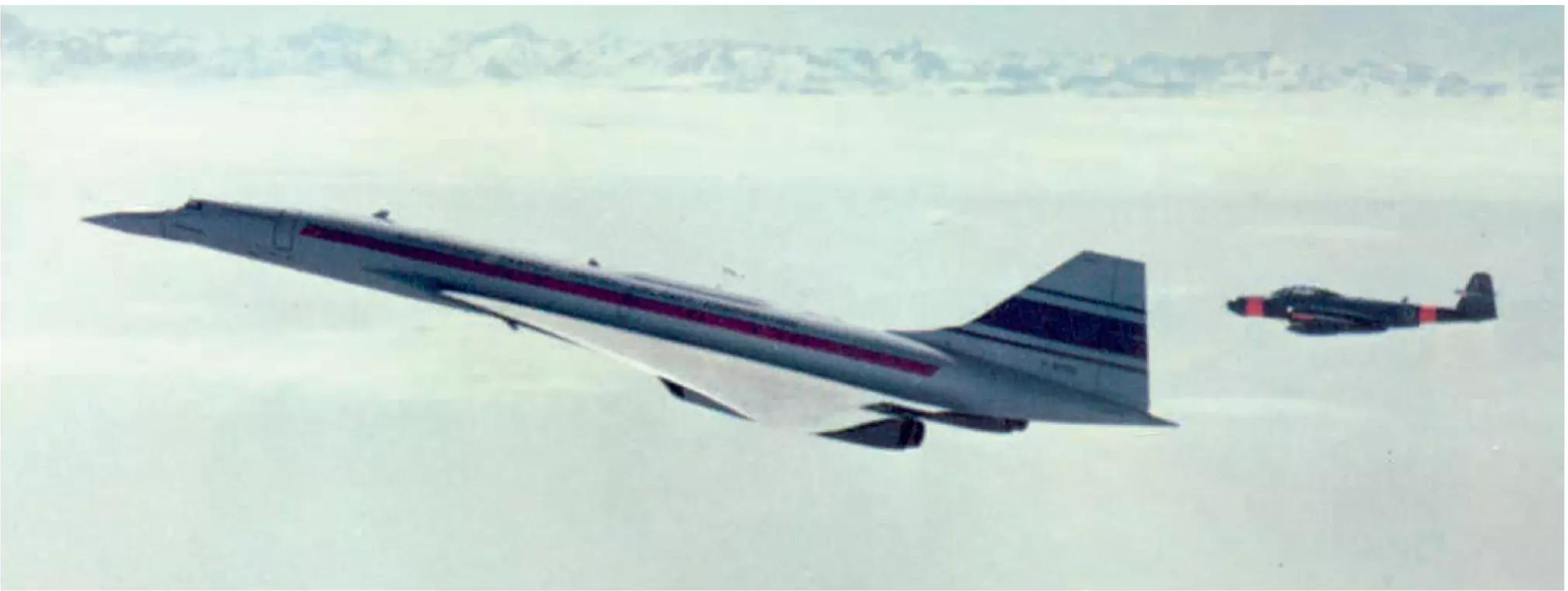
The noise factor made getting into America particularly difficult. By the early 1970s the opposition had led to bans on commercial supersonic flight over the territory of a number of European countries, including Ireland and Germany, plus Canada and the USA. The choice of available routes for supersonic flight had thus become limited to those flown primarily over water. This restriction meant that in January 1976 when Concorde entered service it could only operate on the London-Bahrain, Paris-Rio and Paris-Caracas routes.

Flights were at last permitted into Washington in May 1976, and then a Federal ban at New York JFK airport was lifted. However, opposition to the latter from the 'Emergency Coalition to Stop the SST' saw New York City impose its own ban. However, a Supreme Court ruling subsequently cleared flights into JFK Airport, which proved to be Concorde's greatest success in terms of regular service operations. Relatively light take-off weights, because less fuel was needed for the New York to London run than London to New York, and the airlines ensuring a meticulous application of noise abatement procedures, kept Concorde's take-off noise around American airports to well within the declared limits. This outcome brought an end to the US protests, and as Concorde settled down to its limited flying over the sea the Anti-Concorde Project disappeared as well.

Back in the mid-1960s there was an obvious solution to the supersonic boom problem – to ban commercial supersonic flying overland. Fortunately, the greater part of most of Concorde's important potential routes did lie over the sea, and at the time it was thought that a substantial market for the aircraft would probably remain even if all supersonic flying overland were prohibited. Nevertheless, Britain and France hoped that international air travel might still benefit hugely if properly regulated supersonic flying over land was permitted. It would never happen. ◆

8

Support Aircraft



Gloster Meteor NF.Mk.11 No. 6 of CEV was the chase plane used for most of the early flights of Concorde 001. *JC Carbonel*

In readiness for the Concorde prototypes and for the aircraft's service career a set of support aeroplanes was used to perform background testing and build up the level of technical knowledge in the fields of aerodynamics, powerplant, acoustics and equipment. The most important are described here.

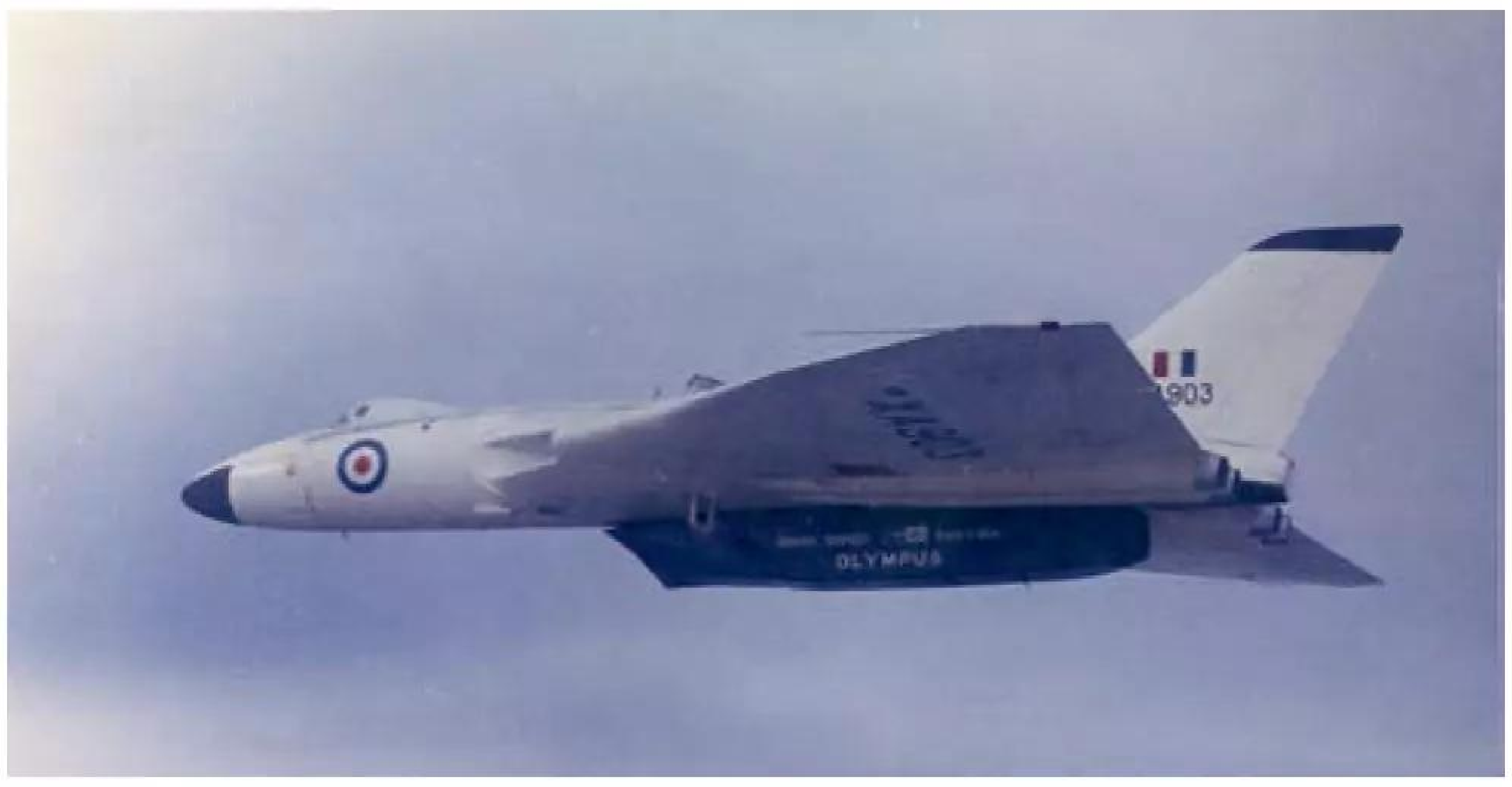
Armstrong Whitworth Meteor NF.Mk.11 No. 6: This French two-seat Meteor was used as a chase plane for the maiden flight of Concorde 001, where it was flown by Gilbert Defer. Earlier that day, 2 March 1969, it had completed some weather calibration flights prior to the take-off authorisation being given to Concorde. Previously, in early 1968 this Meteor had been used for radar calibration at the Toulouse airfield where Concorde was to take off on that momentous flight.

Avro Vulcan B.Mk.1: It was realised quite early in the joint development programme that a flying engine test bed would be needed to assess the Olympus 593's subsonic flight envelope. As a result, Vulcan B.Mk.1 XA903, after being used for Blue Steel stand-off bomb trials, arrived at Filton for conversion on 3 January 1964. This involved the fabrication and mounting of a nacelle underneath the bomber's bomb bay which represented either a number one or number three Concorde nacelle (it did in fact cover some of the features for all four intakes). The Concorde engine pod had a single 'straight-through' intake and in this configuration the Olympus 593 thrust line was a full 7ft (2.13m) below that of the standard basic Olympus units mounted inside the bomber.

The first flight with an Olympus 593 beneath the Vulcan took place on 9 September 1966 and the trials would involve 219 flights, the last of them made on 21 July 1971, totalling 417 hours of flight time, 248 hours of Olympus 593 running, another 109 hours of windmilling and 24 hours of ground running. At one stage a water spray rig was fitted under the Vulcan's forward fuselage to permit water and ice ingestion tests to be made, while over this five-year period six standards of engine and three intake configurations were flown in ten phases of testing.

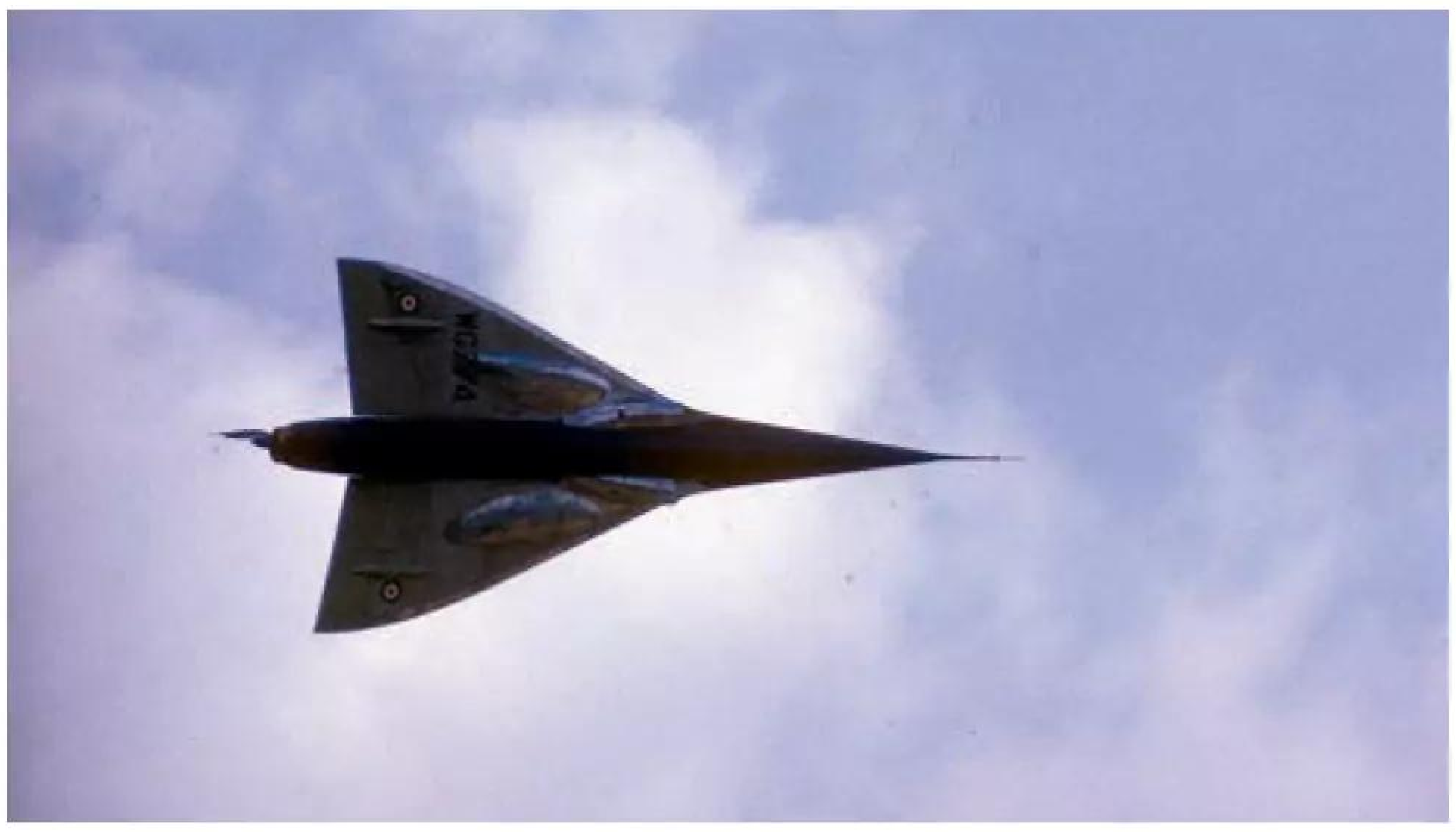
The final phase saw the installation of a -4 engine which was representative of the units to be installed in the first pre-production Concorde 01. The Vulcan flight test bed proved to be the ideal tool for assessing the Olympus 593, in part because of the ease with which flight conditions could be changed. XA903 was used later to test, in a similar installation, the Rolls-Royce/Turbo-Union RB.199 engine developed for the Panavia Tornado Multi-Role Combat Aircraft.

As noted above, Avro Vulcan serial XA890 was used for the trials with the Concorde Take-Off Director.



Avro Vulcan XA903 fitted with the Bristol Siddeley/SNECMA Olympus housing beneath the fuselage. *Bristol Siddeley*

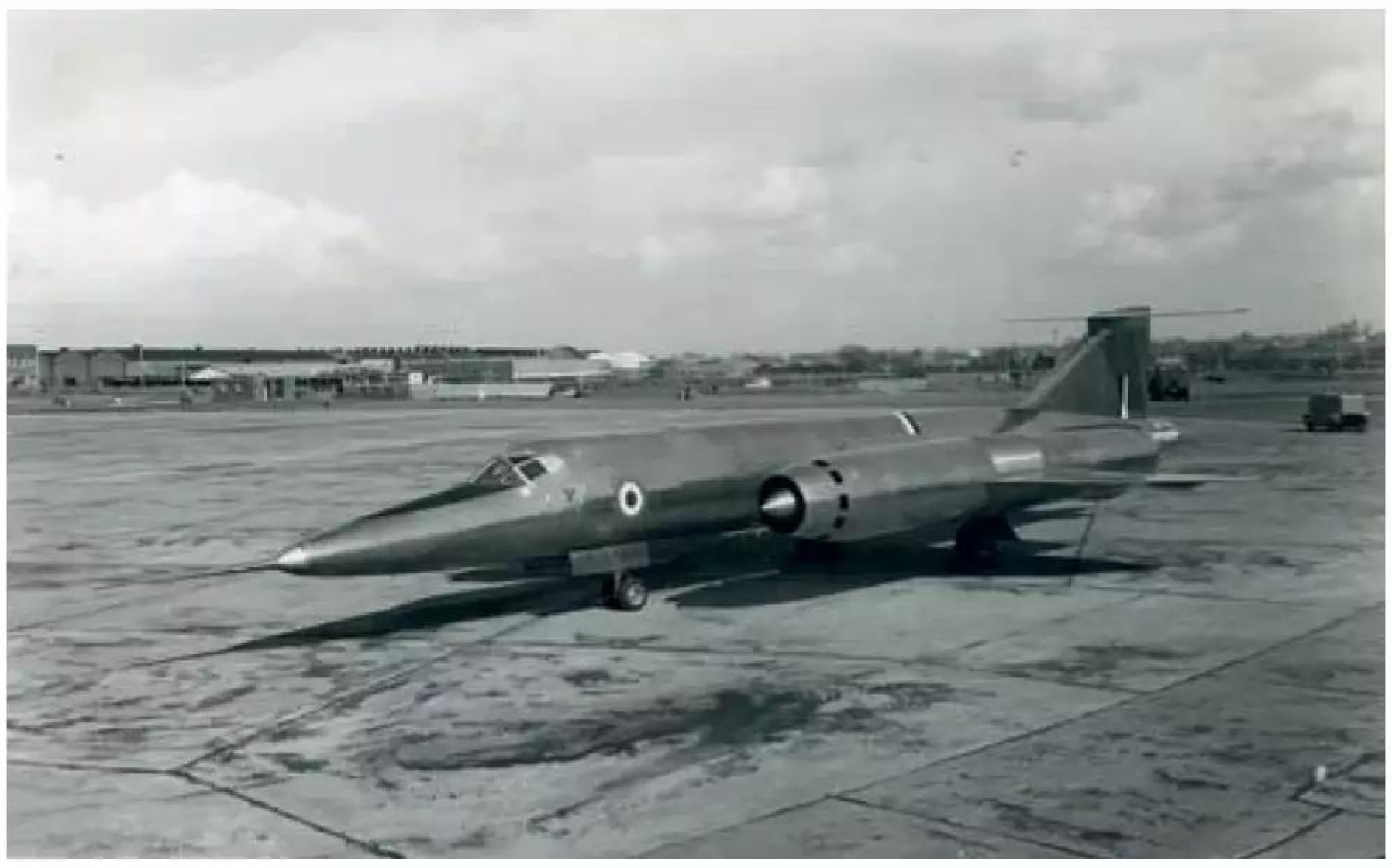
The Olympus 593 Vulcan test bed performing at the September 1968 Farnborough Show. *Terry Panopalis*



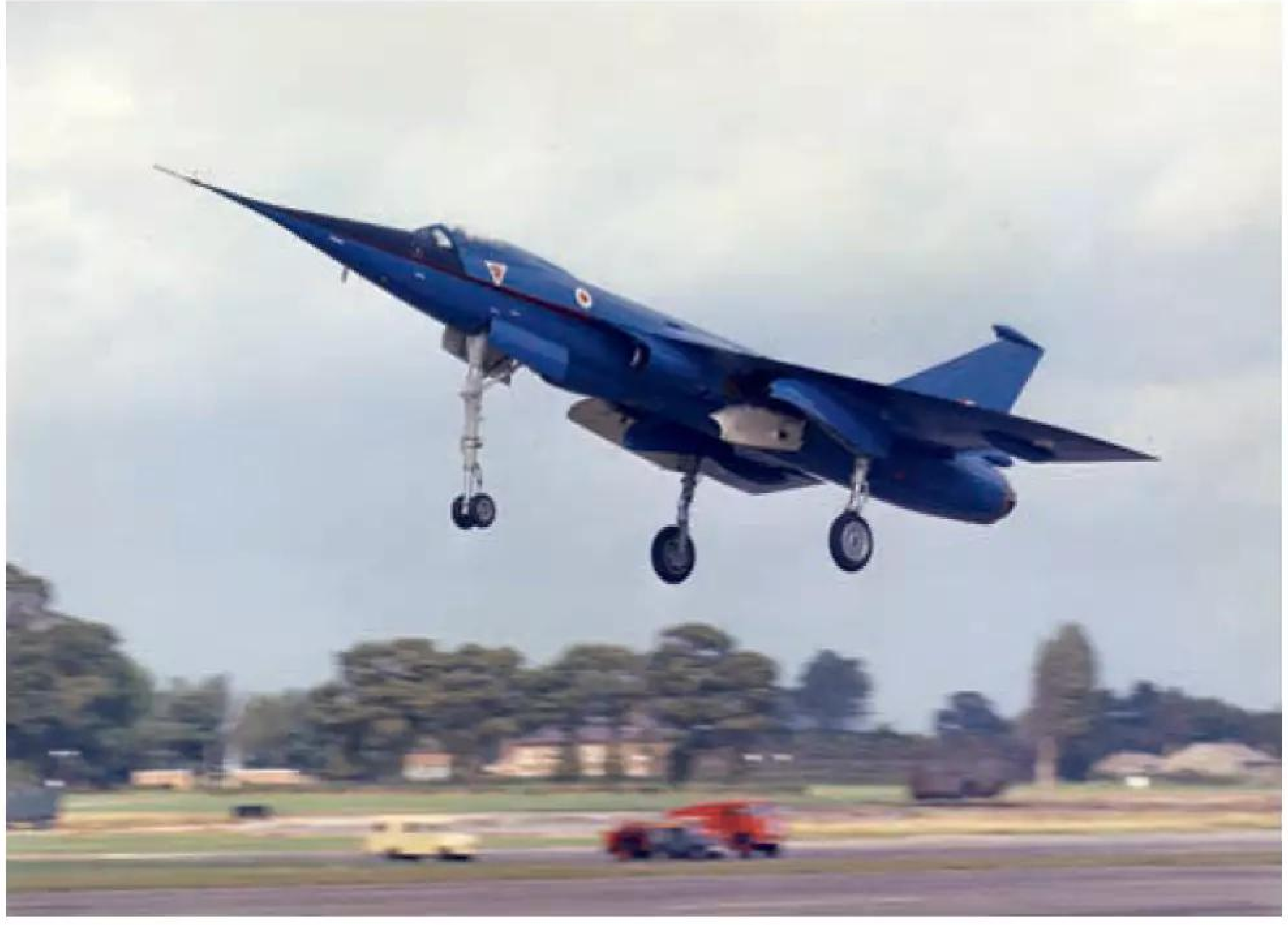
This splendid slide photo of WG774 in BAC 221 form was taken during a flyover made during Farnborough 1964 and shows the ogee-wing superbly. *Terry Panopalis*

Bristol 188: The Bristol 188 was a Mach 2+ research aircraft built in stainless steel and ordered well before the early supersonic transport studies had even begun. It first flew on 14 April 1962 and proved something of a failure, but its high speed flying did provide data which helped the Concorde programme. The introduction of real-time telemetry on this aircraft, where data could be assessed as it happened, was another important advance.

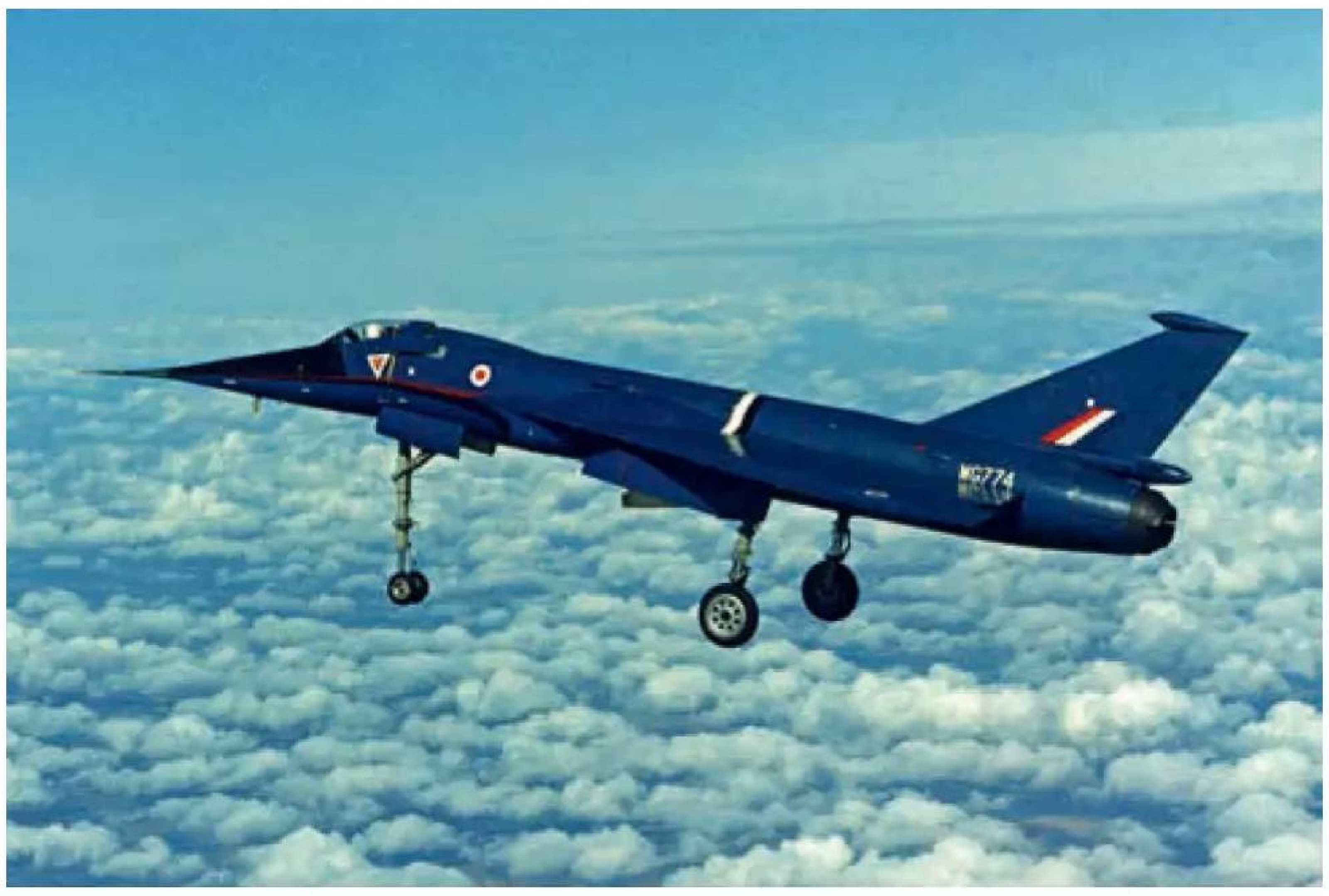
British Aircraft Corporation Type 221: The British Fairey Delta 2 high speed research aircraft was first flown in 1954. The first Delta 2 airframe, serial WG774, was subsequently rebuilt as the BAC Type 221 to serve as a high-speed test aircraft for the Concorde programme, and in particular its wing. The Delta 2's original pure delta wing would not suffice in this role – a full ogee wing was considered necessary to enable a basic investigation into the general properties of slender delta aeroplanes to be made. However, although the 221 appeared to be a Concorde aerodynamic scale model, its wing did not represent a direct scale copy. Concorde's wing was mounted low on the fuselage when the 221's was mid-fuselage, and it had a different twist, camber and droop, and a lower thickness/chord ratio (Concorde wing's droop was required purely for efficiency in cruising flight, and so was unnecessary for this research aircraft).



Bristol 188. *Bristol Aircraft*



Well known but still spectacular view of the BAC 221 in its dark blue paint scheme and again seen taking part in the 1964 Farnborough Show.



The 221 pictured in flight in 1970. *RAE via Adrian Balch Archive*

Type 221's wing was built to explore the behaviour of a slender delta at angles of attack high enough to generate a powerful vortex over the leading edge. The theory behind the slender delta, and subsequent tunnel research, had shown that such a vortex formed from a sharp-edged wing would increase the available lift at these high angles of attack. The new wing was manufactured in port and starboard halves but the majority of the root attachments came from the original Delta 2 fitting.

On this wing there was a straight middle portion to the leading edge (which was swept at an angle of 65°) before it curved away to a streamwise tip. In addition, to ensure an effective separation and the formation of vortices, the leading edge was made sharp and was extended forward along each side of the fuselage as a long chine. The airframe rebuild brought no changes to the fuselage from the engine face aft and to the fin, rudder, airbrakes and reheat installation, but a new 6ft (1.83m) fuselage section was inserted between the engine and the cockpit to accommodate all of the wing.

WG774 arrived at Filton to begin this conversion on 5 September 1960 but the work took far longer than expected and was not completed until July 1963. And because no prior ground testing of its equipment could take place, the aircraft's ground clearance work then took a further ten months.

WG774 made a maiden flight in its Type 221 configuration on 1 May 1964 piloted by Godfrey Auty, but the delays lessened the aircraft's value to the Concorde programme. In general WG774 spent much of its flight time at Filton studying the approach and landing phase of the flying programme. This aircraft was also used to investigate auto-stabilisation and to develop an auto-throttle system for approach speed stability. WG774's very successful flying career lasted until June 1973.

Dassault Mystère IVB: The serial number of this aircraft is unknown. It was used by Société Hispano-Suiza circa 1968 for landing gear tests.

Dassault Mirage IIIA No. 03: This aircraft was used in Operation Jericho during 1967 and 1968, but on 28 October 1968 it crashed at Istres due to a flame out at low altitude and was written off. Previously, on 18 June 1959, this same Mirage III, piloted by Gérard Muselli, had claimed the World Speed Record for a 100km (62 miles) closed circuit with a speed of 1,771km/h (1,101mph).

Dassault Mirage IIIB1 No. 225: This two-seater was first flown in 1964 but was quickly modified as an 'avion de stabilité variable' (variable stability aircraft or VSA) with fly-by-wire control (commandes de vol électriques – CDVE) and special electronic equipment to permit the aerodynamic characteristics and control responses to be varied to emulate the configuration of any aircraft. In this way the Mirage could be given precisely similar handling characteristics to the Concorde.

This facility was installed only in the front cockpit, the rear cockpit being reserved for the 'manager' who set the parameters using the electronic equipment. After preliminary flights by a Dassault crew this aircraft was taken over by CEV on 15 June 1965. In due course it was flown as a flight simulator by many pilots before their opportunity came to fly the Concorde.

Mirage IIIB No. 225 pictured on 19 July 1996 when it was still being operated by CEV. *Philippe Ricco*

The aircraft itself was code-named 'Cyclope'. A first run of Concorde tests was conducted in the second half of 1966 to simulate prototype 001 as it had been designed (and as it was then being built) and the results indicated that the airliner would have a landing speed that was too high (352km/h/190 knots instead of 278km/h/150 knots). The higher figure would be acceptable for a test flight but not for a commercial landing.

In fact the first simulation runs aboard No. 225 were, in the view of the future Concorde pilots, unconvincing compared to those they had experienced in the ground simulator. A report revealed that setting the "parameters for the effects on the control stick of a single-seater fighter to resemble those on a wheel-type control as used on the Concorde is difficult and remains a problem". It was proposed to fit a wheel control in the Mirage, but this idea was also fraught with problems which remained unsolved. The whole of 1967 was spent trying to obtain the same results from the 'Cyclope' and the SudSim ground simulator.

This Mirage was also used to prove the flight test methods adopted for Concorde, and in particular those which were to be used to measure the aircraft's aerodynamic characteristics. Today Mirage IIIB 225 is an exhibit in the Musée de l'Aviation of Saint-Victoret near Salon de Provence, having been acquired from CEV Istres in February 2007.

Dassault Mirage IIIRD No. 363: This aircraft, nicknamed 'Astérix' because of its 'moustaches' (retractable nose surfaces), had been modified as part of the programme to adapt the Mirage III to Swiss Air Force requirements. It had been flown by Swiss pilots in October 1968. In July 1969 it was flown during experiments at low and landing speeds because, at that time, some thought was given towards fitting a similar moustache device to Concorde. However, after tests on a model in the wind tunnel it was decided not to pursue this idea.

Mirage IV No. 04 was rarely photographed, but here the aircraft is seen waiting to begin another test flight (at a snow-covered airfield). *Philippe Ricco*

Dassault Mirage IV 01: In 1961 this aircraft was earmarked for involvement with Operation Jericho, but it may not have done any flying at all in support of Concorde.

Dassault Mirage IVA No. 04: On 15 November 1966 the Ministre des Armées approved the allocation of a Mirage IV prototype to the programme (it was designated 'Mirage IV TSS') and from late 1966 prototype 04 had its military equipment removed (targeting avionics, refuelling equipment, bomb carrying equipment etc.) and test and recording equipment installed (civilian radio, cameras, recorders, etc.). After delivery to the CEV, it was first used to investigate the feasibility of integrating an SST into civilian traffic patterns by making approaches to Le Bourget and Orly airfields. Operating from CEV's Brétigny base it flew different courses above the Channel to simulate different approaches and take-offs from these Parisian airports.

The Mirage IV was based at Brétigny for these tests so it took off from there, entered Orly airspace almost immediately, followed the directions given by the air controller to take the correct route out of Orly, flew its round trip over the Channel and then turned back as if it was intending to land at Orly. It would abort the landing and then, while still in the hands of Orly air control, would fly back to Brétigny.

A total of 15 flights were made during October 1967 and these showed that airport traffic control could cope with the SST (with some changes of procedure), but in addition the transition from supersonic to subsonic flight had to be made over the sea to avoid complaints.

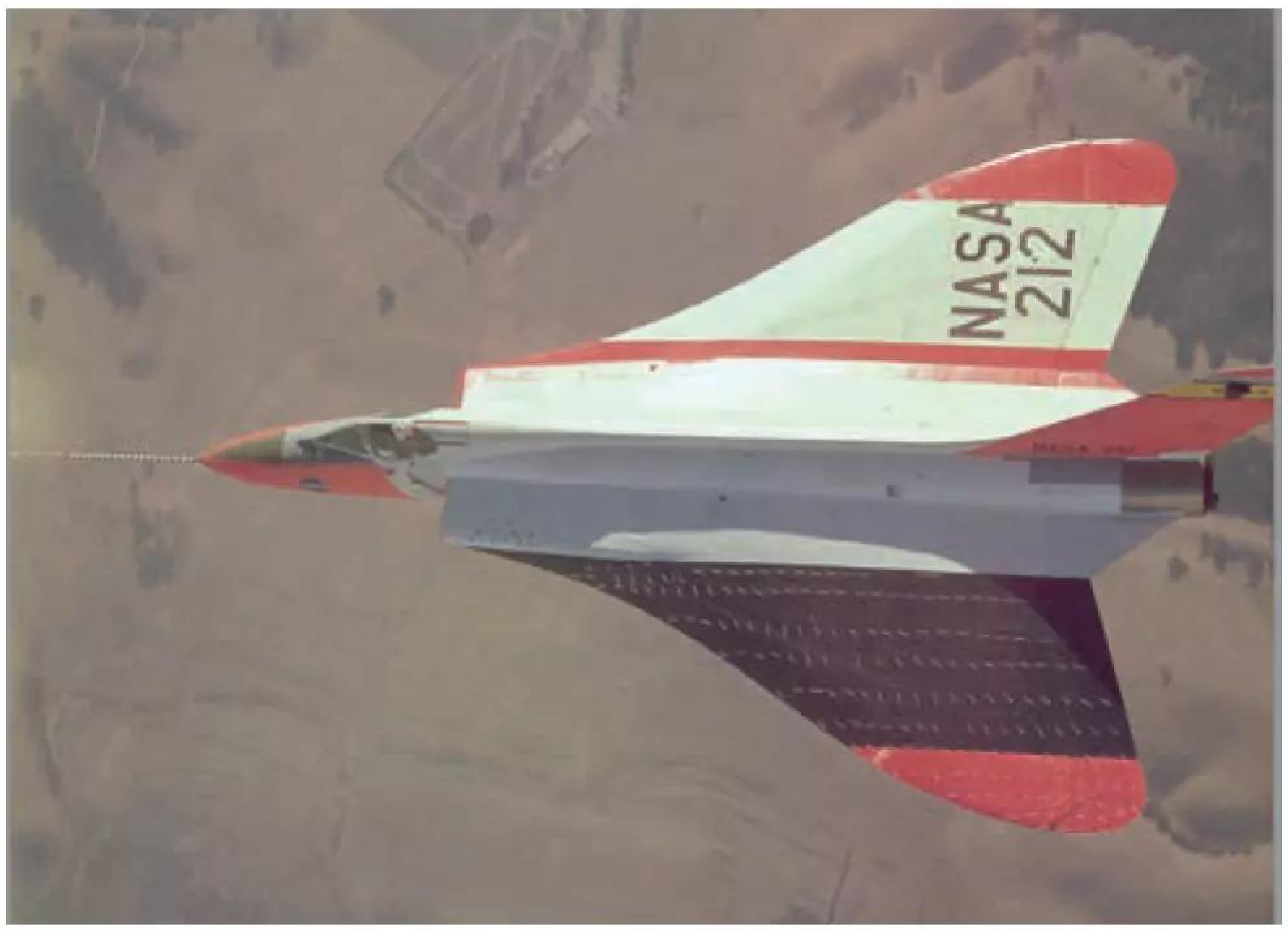
Mirage IVA 04 was also used during preparations for the first flight of Concorde 001, including in 1968 the roles of chase plane, ground support and air control. In parallel it was also used to validate drag measurements, but perhaps the major contribution of this aircraft was the determination of the VMU (minimum take-off speed or minimum flight speed) for 001 on take-off and in zero rate of climb speed (VZRC) experiments. From March 1968 it was fitted with a Concorde-type air data probe, after which it was flown by future Concorde test pilots as part of their training for the airliner's test flights.

One report noted that "a most obvious merit of the choice of this aircraft type is that it is the only one available in France and Great Britain with enough fuel capacity to simulate in real time the flight path of a Concorde, from take-off to Mach 2 and from Mach 2 to landing (while exhibiting the characteristics and performances of the future civil aircraft). It is therefore, technically irreplaceable for test flying and for training Concorde pilots in the techniques that they will be using."

The Mirage IV was also involved in the testing of other important new features in the SST's design such as balancing the aircraft by means of fuel transfer. It flew 40 times from Istres as part of the Jericho campaign and later about another 100 flights from Toulouse for Sud, BAC, CEV, Air-France and ARB pilots. Unfortunately this aircraft crashed on 23 October 1968 with Pierre Dudal of Air France and Pierre Caneill on board. Thanks to their ejector seats both escaped but were injured.

The cause of the crash was a flame-out at low altitude during a 'passage à la tour' (flight in front of an airfield control tower) and Dudal had to pilot the machine as a glider to avoid crashing into an inhabited area of Toulouse. Altogether, before its crash, Mirage IVA 04 had contributed 152 flights to the Concorde programme.

Douglas F5D Skylancer: In 1965 ONERA collaborated with NASA in the USA in the testing of a full-scale slender delta or 'Ogee wing' on a Douglas F5D Skylancer fighter. The Skylancer was first tested in this form in the Ames 40ft by 80ft (12.2m by 24.4m) wind tunnel, and then undertook several flights to validate the results obtained in the tunnel. NASA's report describing the trial stated that, in the opinion of the pilot, the modified aircraft had improved the lateral-directional control and damping characteristics.



The Skylancer used to flight test the ogee wing, as part of the co-operation between NASA and ONERA, was 'NASA 212', originally BuAer No. 139208. *NASA*

Canberra WJ627 flew as the chase plane for 002's first flight in April 1969. *Dave Forster*

In 1973 WJ627 was replaced in its duties as a Concorde support aircraft by WH793. *Terry Panopalis*

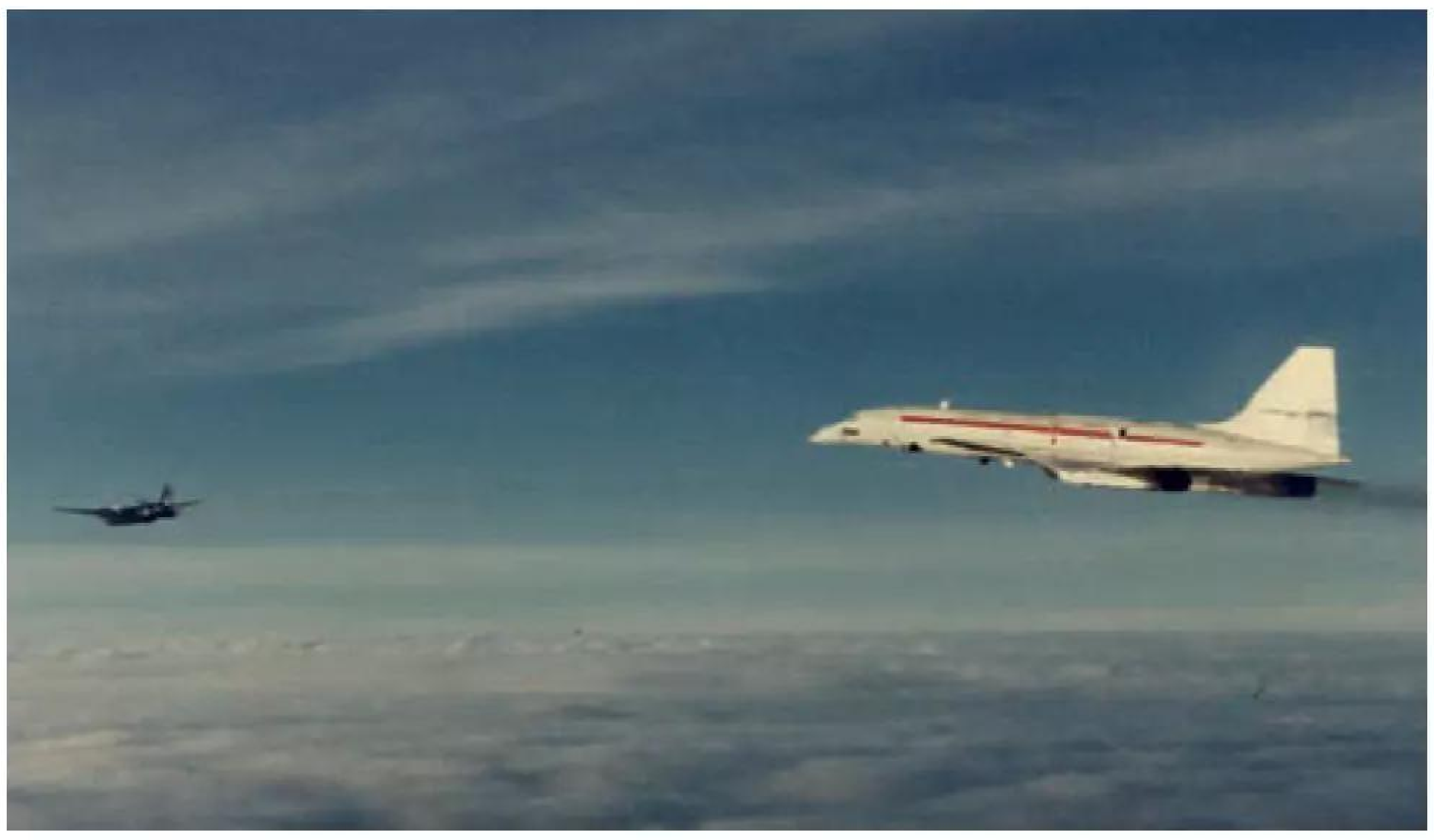
At high angles of attack, beyond 15°, a slight lateral unsteadiness was observed and, although this feature did not increase significantly at even higher angles of attack, it was considered to be an indication of the limiting angle available for the approach to land. Overall, the Skylancer's lateral-directional flying qualities with the Ogee wing (when compared to its original delta-type wing) had improved sufficiently to permit a reduction in the approach speed of 10 knots (18.5km/h).

English Electric Canberra: Several English Electric Canberras found employment supporting the Concorde flight test programme. The chase aircraft for the first UK prototype flight in 1969 was B.Mk.2 WJ627, though this aircraft had been allotted to BAC for Concorde chase duties and Concorde pilot flying training in July 1968. It continued in these roles right through until August 1972, except that another B.Mk.2 WG789 served briefly as a stand in at Fairford between 8 July to 6 August 1971 when WJ627 was unavailable. B.Mk.2 WH793 took over WJ627's role in August 1973. In addition WV787, a B(I).Mk.8, was used at Boscombe Down for icing trials with other aircraft types well into the 1980s, and this included Concorde during its trials flying.

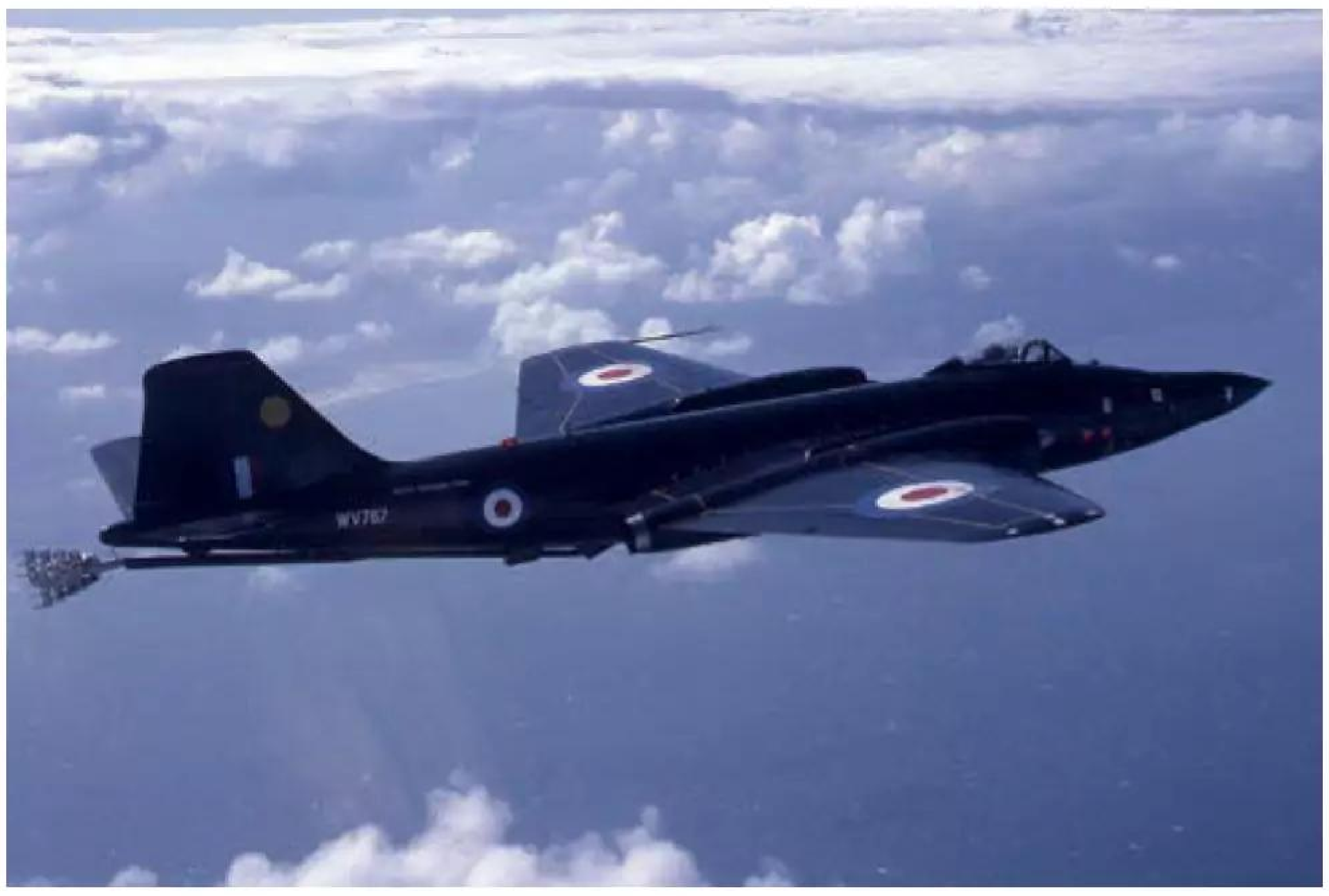
Handley Page HP.115: At one of the first meetings of STAC a decision was made to fund the development of test bed aircraft and an experimental flight programme to assess the slender delta's performance in the air. One of the research types built was to be the BAC 221 and the other was the Handley Page HP.115.

The original plan had been to build a glider for the low speed assessment and in early 1959 a design competition was held against Specification X.197T. However, the winning HP.115 was from the start built as a powered machine since this would make it a much more practical and useful research tool. Just one example was ordered, military serial XP841, and the covering requirement stated that it was to operate at heights up to 15,000ft (4,572m) above sea level.

Built almost entirely in light alloys (in part because wood produced a heavier airframe), and with a pure delta wing rather than the SST's 'gothic' form with the leading edge swept to a constant 74° 42´, the HP.115 was a relatively simple machine. Its power unit, a single Armstrong Siddeley Viper jet, was mounted in a nacelle on the upper rear fuselage and there was a fixed tricycle undercarriage. The installed test equipment would record time, indicated



English Electric Canberra WV787 was fitted out as a tanker by A&AEE Boscombe Down for icing trials with other aircraft types, including Concorde as seen here. Water was sprayed from a bar that ran under the rear fuselage and from nozzles positioned beneath the two jet exhausts. *A&AEE via Terry Panopalis*



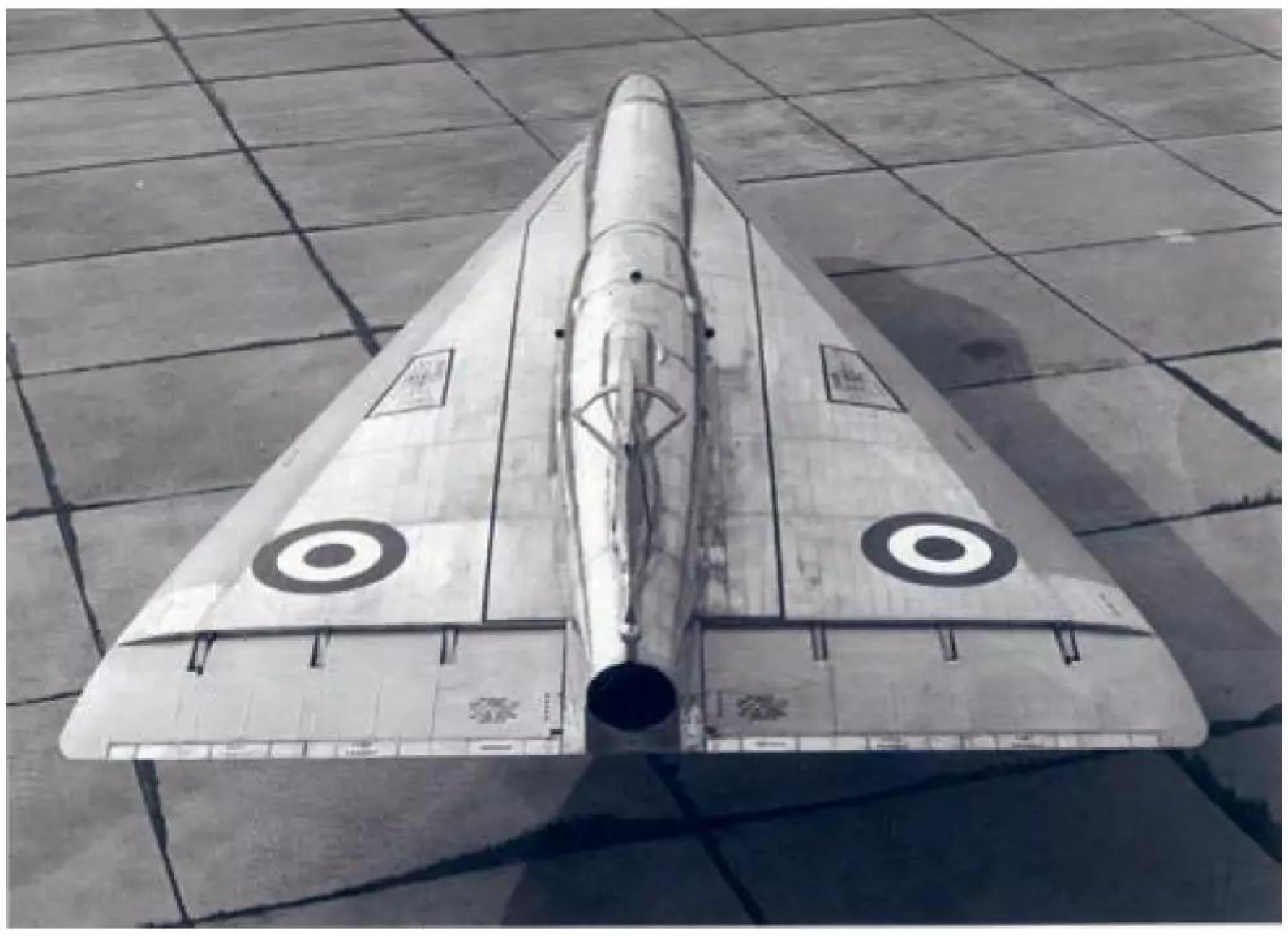
Close-up photos taken in April 1982 showing WV787 with the fittings used for water-spray trials. *A&AEE via Terry Panopalis, Adrian Balch Archive*

In June 1967 English Electric Lightning XN725 was used to simulate Concorde's climb profiles, since the fighter was the only British aircraft with a suitable performance for the role. For this work the aircraft operated out of RAE Bedford. In this photo, taken in about 1962, XN725 is seen during trials with overwing fuel tanks.

speed, height, angles of flying control surfaces, angles of incidence and side slip, rates of pitch, roll and yaw, normal and lateral accelerations, and elevator stick forces; the airflow over the wing could also be observed by having smoke injected into the core of the vortex.

The HP.115's maiden flight took place on 17 August 1961, piloted by Sq Ldr Jack Henderson, and a couple of months later XP841 became part of RAE Bedford's Aerodynamics (or Aero) Flight. With its high wing sweep angle this aircraft was intended to exaggerate the low speed handling problems expected from the slender delta, but pilots reported that it was a most reasonable aircraft to fly, and this without any artificial aids.

Its longitudinal stability and handling were excellent and control was easy, even during flight at speeds as low as 70mph (113km/h) with the angle of incidence approaching 30°. The lateral control was also very good but would deteriorate with loss of speed or in turbulence and then the HP.115 would experience a phenomenon called Dutch roll (a simultaneous oscillation in both the rolling and yawing planes). This could give bank oscillations of +/-60° but it would not affect Concorde because the airliner would land at a higher speed than that when Dutch Roll became present on the HP.115.



The HP.115 displays its long slender wing and trailing edge elevons in a picture which, it is understood, was made before the aircraft had flown. *Handley Page Association*

The HP.115 XP841 photographed during test flights, it is thought during 1961. *Handley Page Association*

SE-XBZ
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The prototype MS 760 Paris III seen on the tarmac at Le Bourget in 1965. Four years later this prototype had been bought by Sud Aviation and was used to film the first flight of Concorde 001. *Philippe Ricco*

The D-6 rocket was used to launch aerodynamics model of the SST as part of the ONERA trials programme. *ONERA via JC Carbonel*

Much of XP841's work involved a detailed analysis of vortices and as such it proved to be the ideal 'classroom' to conduct work like this. Test pilot John Farley said that the HP.115 was a beautiful aircraft to fly at low speeds. With the resulting flight test data RAE Bedford was convinced that the slender delta would prove fine for the Concorde. XP841 itself continued to fly until August 1973, in all it completed at least 1,060 flights and subsequently went into preservation.

Morane-Saulnier MS 760 C-1 Paris III: This aircraft made its first flight on 28 February 1964. The prototype was not taken further but it was used by Sud as chase plane to film the Concorde's first flight. The pilot on this occasion was test pilot Max Fischl and having the cameraman on board (from the French television channel ORTF) meant that the entire flight could be transmitted live.

ONERA D-6 Rocket: Five of these rockets were launched during 1965, each with a Concorde model fitted on top. The objective was to test the airliner's wing profiles at Mach 2.2.

Sud SE 210 Caravelle No. 116 (Civil Registration F-ZACE): Employed on Concorde work from 1966 until 1969, this Caravelle was at one stage used by Société Hispano Suiza to test landing gear brakes. It was also used for navigation trials, for example on 15 October 1968 (here under the auspices of the British Ministry of Technology and the RAF) with Sud's Jacques Guignard and BAC's Brian Trubshaw aboard and with Gilbert Defer at the controls. On 18 December 1968 the Ferranti-SAGEM SF 500-AESI inertial navigation system, as fitted to the Concorde prototypes, was installed in the Caravelle and the testing of this equipment lasted until 6 February 1969. In the end 31 flight hours were completed without problems and with drift staying constantly below 1.5nm (2.8km/h) per flight hour. ◆

In-flight view of Sud Caravelle No. 116, civil register F-ZACE, as used by the CEV. In the French registry system the letter 'Z' is used to designate an experimental aircraft. *Philippe Ricco*

Flight Testing

9

By Tony Buttler and JC Carbonel

BRITISH AIRCRAFT CORPORATION - SUD AVIATION FRANCE
375
F-WTSS
F-WTSS

Beautiful photograph showing Concorde prototype 001/F-WTSS flying over Paris in June 1969. *Alan Jenner*

PROTOTYPES

The construction of the two Concorde prototypes began in April 1965 and the roll-out of the first, 001 bearing the registration F-WTSS (Transport SuperSonique), took place at Toulouse on 11 December 1967 in front of a thousand guests. Those in attendance included senior officials from the two contributing governments, potential customers and the manufacturers.

The first set of ground runs at Toulouse was made in February 1968 and lasted three weeks. Finally, at last, after repeated slippages in the planned date, and after 33 ground tests runs, the big moment arrived on 2 Mach 1969 when Concorde 001 made the airliner's maiden flight. This took place in the presence of Henri Ziegler, head of Sud Aviation, Sir George Edwards, head of BAC, and over 400 international news reporters.

The take-off had been delayed a number of times due to poor weather, but now the sky cleared and at 3.15pm the Olympus engines were started in their intended order, 3, 2, 4 and 1. *Informations Aéronautiques* reported how "ten minutes later the prototype began its majestic roll on the [taxi] track and then at 3.40pm the aircraft began its take-off run. Two chase aircraft had already taken-off: a Meteor from CEV and an MS 760 Paris from Sud Aviation. At take-off the wind was blowing 10 knots (18.5km/h) from the rear, yet Concorde's run was still only 1,400m (4,600ft) before it became airborne, 25 seconds after removing the brakes."

The flight lasted 29 minutes and was witnessed by thousands of spectators in the lanes and fields around the airfield and by a vast television audience both in France and in Britain; the latter included air-to-air views from the Paris camera plane. The flight was made with undercarriage down and nose drooped throughout and 001 landed with its Meteor NF.Mk.11 chase aircraft still in close company on its starboard side and the Paris photographic aircraft to port.

A picture taken during 001's roll-out ceremony held at Toulouse on 11 December 1967.

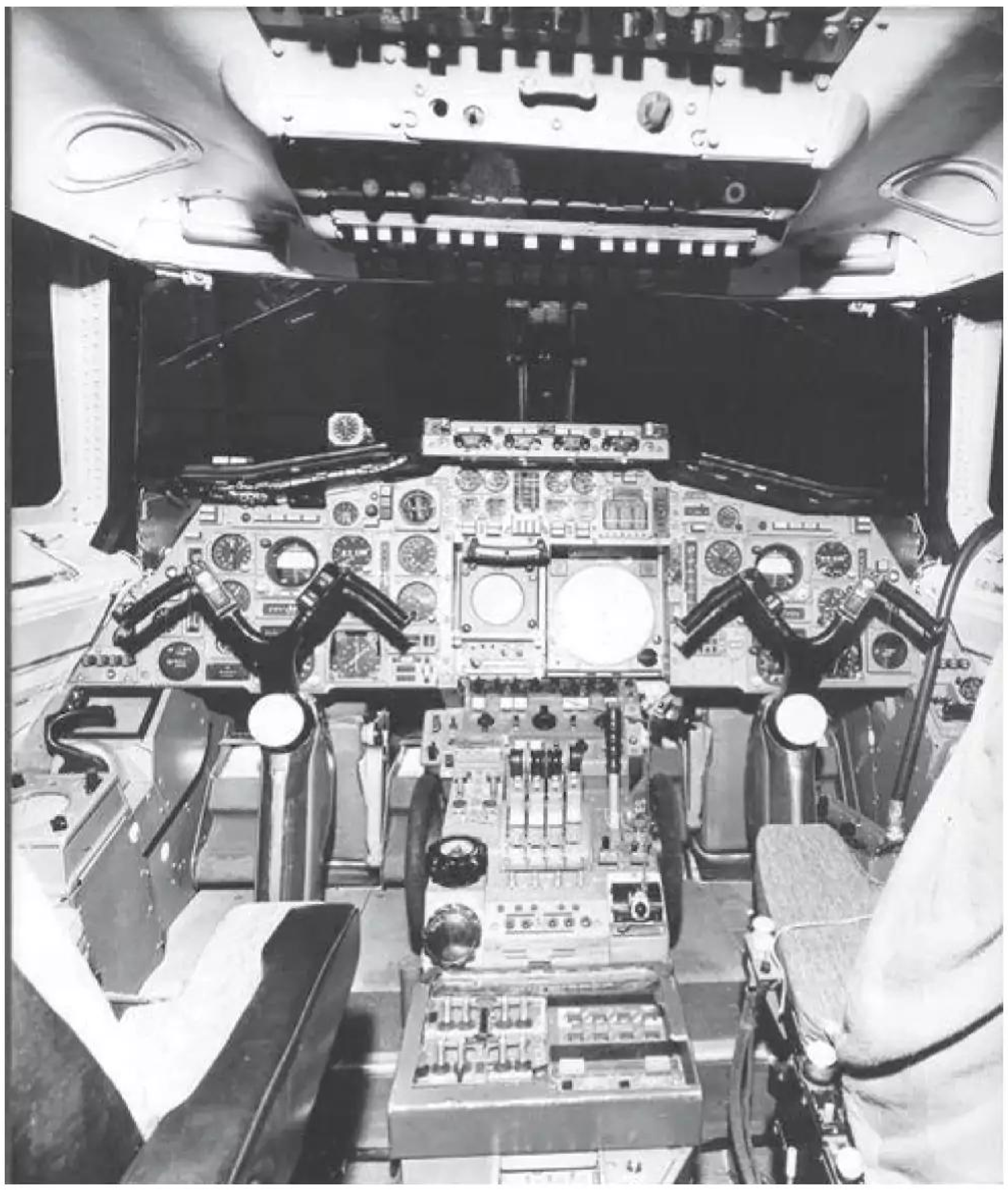
Prototype 001 parked on the ramp at Toulouse is readied for a flight in 1969. *Sud Aviation via JC Carbonel*

For the flight, 001 had -3B engines installed and these generated a lot of smoke when reheat was lit. 001 had been flown on an extended left-hand circuit and the maximum speed and height reached was 250 knots (463km/h) and 10,000ft (3,048m).

Afterwards flight test director André Turcat said "the machine flies and she flies well. That is the result of many months of work which had not always been well appreciated, and was even sometimes criticized. Today our work methods are validated by this aircraft which has given us everything we expected of her".

The test equipment installed on board weighed 13 tons and recorded over 3,500 elements of data, and the crew comprised Turcat (first pilot), Jacques Guignard (co-pilot), Henri Perrier (flight engineer) and Michel Retif (flight mechanic). The back-up crew had been Jean Franchi, Claude Durand and BAC chief test pilot Brian Trubshaw.

The first flight of the British prototype 002, registration G-BSST, followed in April and the delays in 001 getting airborne had enabled work on the second machine to catch up following 002's roll out at Filton on 12 September 1968 in a rather low-key ceremony. On 9 April 1969, on what was first intended to be a final high-speed taxi test, Trubshaw converted this into 002's first take-off, on which it was accompanied by a Canberra chase aircraft. Again there were clouds of dark smoke (a characteristic of the prototype's engines) but when 002 became airborne at 2.24pm at an approximate weight of 240,000lb [108,864kg]) it (according to *Flight* magazine) lifted gently and flew smoothly away.



View showing 001's cockpit. *Sud Aviation via JC Carbonel*

Both prototypes had the -3B engine standard with thrust ratings of 34,370lb (152.8kN). The crew for this 25-minute trip was Trubshaw, John Cochrane (co-pilot), B G Watts (flight

Concorde prototype 001 takes off, possibly on its maiden flight.

Seen during its maiden flight, 001 is photographed against a background of the city of Toulouse with the CEV Meteor chase plane behind. Throughout this first flight 001's nose was held at 12.5° down (the landing position). *Sud Aviation via JC Carbonel*

The French flight test crew in front of 001 on 2 March 1969 after the first flight of Concorde. Left to right are flight engineer Henri Perrier, test pilot Jean Guignard, chief test pilot André Turcat and flight engineer Michel Rétif. *Copyright AIRBUS/AIRITAGE/D.R*

Concorde 002/G-BSST's low-key roll-out ceremony was held on 12 September 1968. Note that the fin and rear fuselage honeycomb structure has still to be skinned over.

engineer) and flight observers P A Holding, J C Allan, and M R Addley. The aircraft landed at Fairford in Gloucestershire which was to be the base for the flight test programme (and far more suited for this work than noise-sensitive Filton).

Both radio altimeters failed to operate as the aircraft was prepared for its first landing and so Trubshaw had to judge the height entirely for himself on the run in. Fairford's role in the test flying and the training of the first British Airways pilots would continue until November 1976.

The planning of the flight test programme had started much earlier and was first outlined by the manufacturers in September 1964. There would be three overlapping phases, the early development flying, then detailed flying in preparation for flight certification, and finally endurance flying to make the aircraft ready for the airline routes.

The initial tests would assess the aircraft's general handling and explore the full flight envelope, its structural integrity, in-flight resonance characteristics, and then engine and performance tests. In addition, all of the aircraft's systems and equipment would have to be tested and cleared for service use. The overall objective was to find and eliminate problem areas and then deliver an airliner that the airlines could operate without problems.

For this work 001 and 002 were very similar and had practically identical test equipment installed, although 001 also an additional resonance test facility which would allow the aircraft to explore the Concorde flight envelope (it would also assess the autopilot and navigation systems). During the first phase 002 would concentrate more on testing the Olympus powerplant, establishing performance characteristics as well as testing the electrical and fuel systems.

The airframe standard used for 001 and 002 was not as good as that necessary for airline service and as a consequence the safety factors were reduced. During phase two, for certification flying, the full flight envelope would be analysed again but this time systematically and in more detail and using pre-production aircraft of a standard that would almost meet the requirements of production machines. Phase three would to all intents and purposes mirror airline operations, not just assessing and flying routes but employing standard turn around procedures, etc.

The people perhaps most associated with Concorde in all aspects must surely be the two chief test pilots, Turcat and Trubshaw. Turcat had served with France's air arms during the Second World War and the Indochina War, before

This BAC photo shows 002 taking off for its first flight. The angle is very similar to the earlier view of 001 taking off, affording the opportunity to compare the two aircraft.

You can almost hear the noise as 001/F-WTSS rolls down the runway.

001/F-WTSS with its drag chute deployed taxis in after another flight. *Richard Curtis*

being assigned to EPNER (École du personnel navigant d'essais et de réception), the French test pilot school. Prior to Concorde, his most high profile task had been testing the Nord 1500 Griffon ramjet-powered research aircraft prototype, in which he set a new world speed record over 100km in February 1959. Turcat then joined Sud Aviation where Concorde would dominate his life for many years. He retired from active flying in the late 1970s and died in January 2016.

Brian Trubshaw had joined the RAF in 1942 and flown with both Bomber and Transport Commands. Post-war he joined the King's Flight before in 1950 becoming a test pilot with Vickers Armstrong where he flew a succession of large aeroplanes, the Valiant jet bomber and then the Vanguard, VC.10 and BAC 111 (One-Eleven) airliners. This experience left him well placed to lead the British Concorde flight test team. Trubshaw retired in the 1980s and died in March 2001.

Both prototypes were demonstrated to the public for the first time in early June 1969 at the Paris Air Show, 001 being based at Le Bourget and 002 flying over from Fairford for each display (the Boeing 747 was also introduced at this show). By 20 June the two Concorde prototypes had completed 34 flights (22 by 001, 12 by 002) with a total block time of 48 hours 22 minutes and they were acquiring test data at a rapid rate.

Aircraft 001 had now embarked on in-flight flutter testing while 002 was being fitted with variable auxiliary air intakes in place of the fixed vanes that had so far sufficed for subsonic flying, a modification which would allow the flight envelope to be extended from Mach 0.8 up to Mach 2. As an illustration of what was being covered, Flight 5 made on 21 March had seen 001 taken to a speed of 350 knots (648km/h) before engines 2, 3 and 4 were individually shut down and then relit, while Flight 7 on 30 March saw a measurement of the rate of climb after a simulated failure of No. 4 engine.

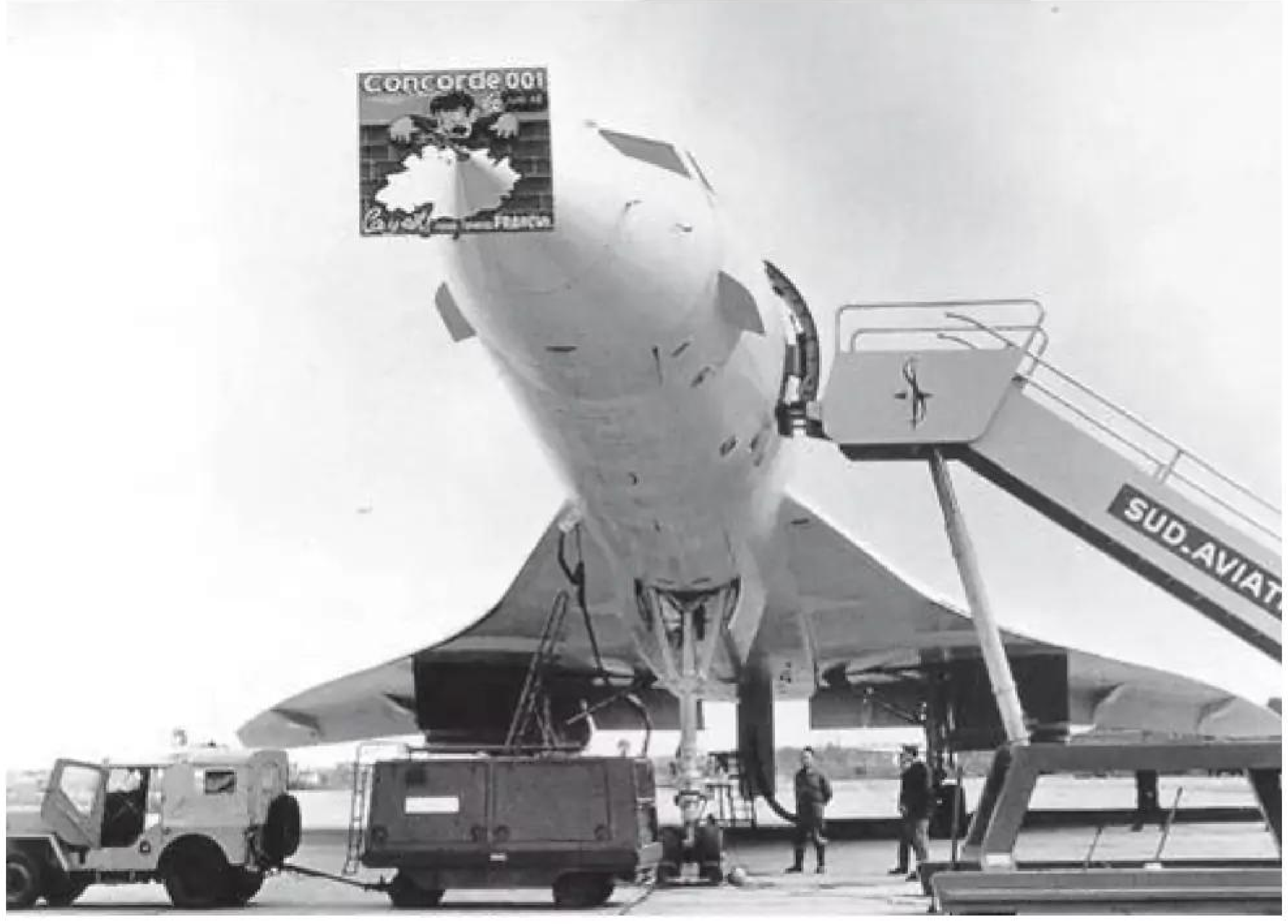
On 1 June 1969 002 flew to an altitude of 30,000ft (9,144m) at Mach 0.80 and it then made a landing on a wet runway. The first flutter test was made on 13 June, and on 10 July 001 recorded Mach 0.90 at 40,000ft (12,192m).

By 24 July 1969 the total of Concorde flights had reached 49, the flight time 76 hours and the highest flight Mach number was 0.94. 001 had continued to confirm the absence of flutter within the flight limits covered so far and, after its period of modification, 002 was now flying again with its newly installed 'barn-door' auxiliary air intakes (the first flight with these was on 18 July). 002 was also exploring aft-cg handling with the help of the rear (No. 10) fuel tank. At 11 August 1969 both Concorde prototypes had completed the subsonic phases of their flight test programmes, the flight envelope having been extended to Mach 0.95.

001 was now grounded for the installation of its 'barn-door' auxiliary air intakes which had by now been proved in flight by 002, and for the commissioning of the rear (No. 10) fuel tank, and it flew next on 21 September. On 7 August, 002 entered a major grounding period for the incorporation of flying control modifications, the installation of the fully variable geometry intake control system, and for engines changes (on its second flight made on 7 August prior to grounding Turcat was in 002's left-hand pilot's seat while Sir George Edwards sat in the navigator's seat).

Forced excitation (flutter) tests in subsonic flight were now virtually complete and had been backed up by two days of supplementary ground vibration tests at Toulouse. On the resumption of its flying 001 had one further check to do at Mach 0.95 and also needed a few flights to verify that the flutter results would remain satisfactory after the installation of fuel tank No. 10. After that everything would be clear to go supersonic.

Prototype 001 F-WTSS made the first supersonic Concorde flight on 1 October 1969, in fact 001's 45th flight in all and the sixth since it had resumed flying on 21 September. Pilot Jean Pinet was very surprised to be selected having expected André Turcat to lead on this flight (Turcat was aboard). Pinet recounted later how the mood aboard the aircraft was quite serious – "the nose fairing was up, the



F-WTSS adorned with a cardboard panel proclaiming its first flight over Mach 1. This landmark was achieved on 1 October 1969. *Sud Aviation via JC Carbonel*

Lovely underside view of G-BSST. Note the small nose strakes.

Concorde 002 taxis with the brake chute open.

cockpit was quite silent with the metal fairing up, and the view ahead was minimal".

Then Michel Defer, who was flying the Mirage III chase plane, exclaimed on the radio "hey boys, I read Mach 1!" "So do we!" replied Pinet who had accelerated F-WTSS up to 1.05 to make certain that the aircraft had passed through the sound barrier. This was about 80 miles (129km) north of Toulouse but crossing this barrier was no relaxed affair because, as Jean Pinet said some years later, "it was not just the crossing of a symbolic step, the phenomena occurring between Mach 0.95 and Mach 1.05 were still somewhat unknown and we were not completely confident of the validity of the many wind tunnel tests which had been done."

Turcat and Pinet reported that the handling and thrust margins were in fact satisfactory at this speed. Overall the flight covered handling with and without auto-stabilisation and a simulated engine failure at Mach 1.05 (an engine was cut suddenly to investigate Concorde's behaviour in the event of an engine loss). Supersonic duration was about 9 minutes at 36,000ft (10,973m) with 2 engines at full power in afterburner and 2 running at reduced power.

After this breakthrough flight the crew posed for a photograph under 001's nose probe, on which had been pinned a cardboard representation of the sound barrier.

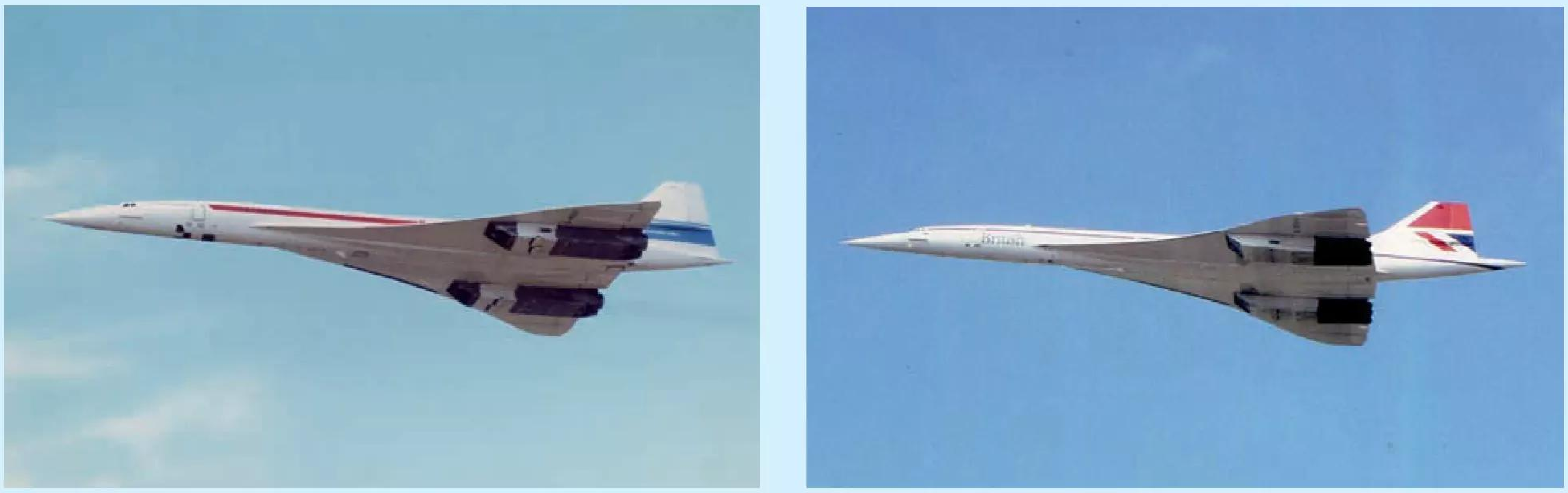
One of the British Concordes takes off leaving smoky trials. Production Olympus engines introduced a modified combustion chamber to help eliminate these emissions.

(It should be noted that this was not the first occasion when a commercial passenger aircraft had exceeded Mach 1. A McDonnell DC-8 had first achieved this distinction in a dive on 21 August 1961 during a test flight.)

From here 001 would press on with flight envelope clearance until it met any limitation imposed by the flying controls or by the air intake geometry. 002 would in the meantime have received further modifications in these respects and the second prototype would then continue to extend the envelope from that point. By the time 100 block hours of Concorde flying had been recorded, and with 63 flights behind them, the two aircraft were showing themselves capable of flight readiness whenever their programme of work so dictated. Indeed, on several occasions an aircraft had flown twice in the same day and the most recent testing had included three-engine approaches and overshoots and two-engine approaches.

On 14 October 1969 001 made its fifth supersonic flight which included 40 minutes at Mach 1.15, bringing Concorde's supersonic testing time to about three hours, while the aircraft's flying programme had been progressing at an above-target rate of 30 hours per month. By 3 November 001 had extended Concorde's flight envelope to Mach 1.25 at 45,000ft (13,716m). Five-and-a-half hours of supersonic flying had been completed, all of it over land, and no complaints had been received in regard to sonic booms. Successful taxi tests had also been made at night in preparation for a forthcoming nighttime test flight, a trip which in fact presented no problems.

Between 8 and 10 November 1969 prototype 001 was flown on behalf of the present customer airlines by pilots from Pan American, British Overseas Airways Corporation, Trans World Airlines and Air France. Their report noted: "After take-off the aircraft was climbed to 27,000ft (8,230m)



Two similar photos which provide the opportunity to compare British prototype 002 and a British Airways production aircraft. The most obvious difference is the extended rear fuselage. *BAE SYSTEMS Heritage, Farnborough*

and flown at Mach 0.9 while fuel transfer to give the supersonic centre of gravity was carried out. Reheat was then selected with full power and the aircraft climbed at 360 knots (667km/h) reaching Mach 1.0 at 34,000ft (10,365m) and Mach 1.2 at 43,000ft (13,105m). After a period of supersonic cruise at Mach 1.2 one engine was cut so that the effect on handling could be observed, and the aircraft descended. At 28,000ft (8,535m) the engine was re-lit, and we were then asked to nominate any other failures which we would like to see. This was called 'failures a la carte'! At 12,000ft (3,660m) various approach configurations were flown and then a descent was made to 2,500ft (762m) for approaches to runway 33L at Toulouse."

On the first day (with Pan Am and BOAC crew) the wind was strong with gusts and was angled across the runway, in other words a good representative airline day. The first landing approach was flown without auto throttle and ended with an overshoot at 200ft (61m). The second approach represented the worst handling case the pilots were likely to face (an extremely remote situation) where the flying controls were in mechanical mode, there was no auto-stabilisation on any axis, and no auto throttle. The third approach included no 'failures' but did lead to a touch and go landing followed by an engine failure at lift off.

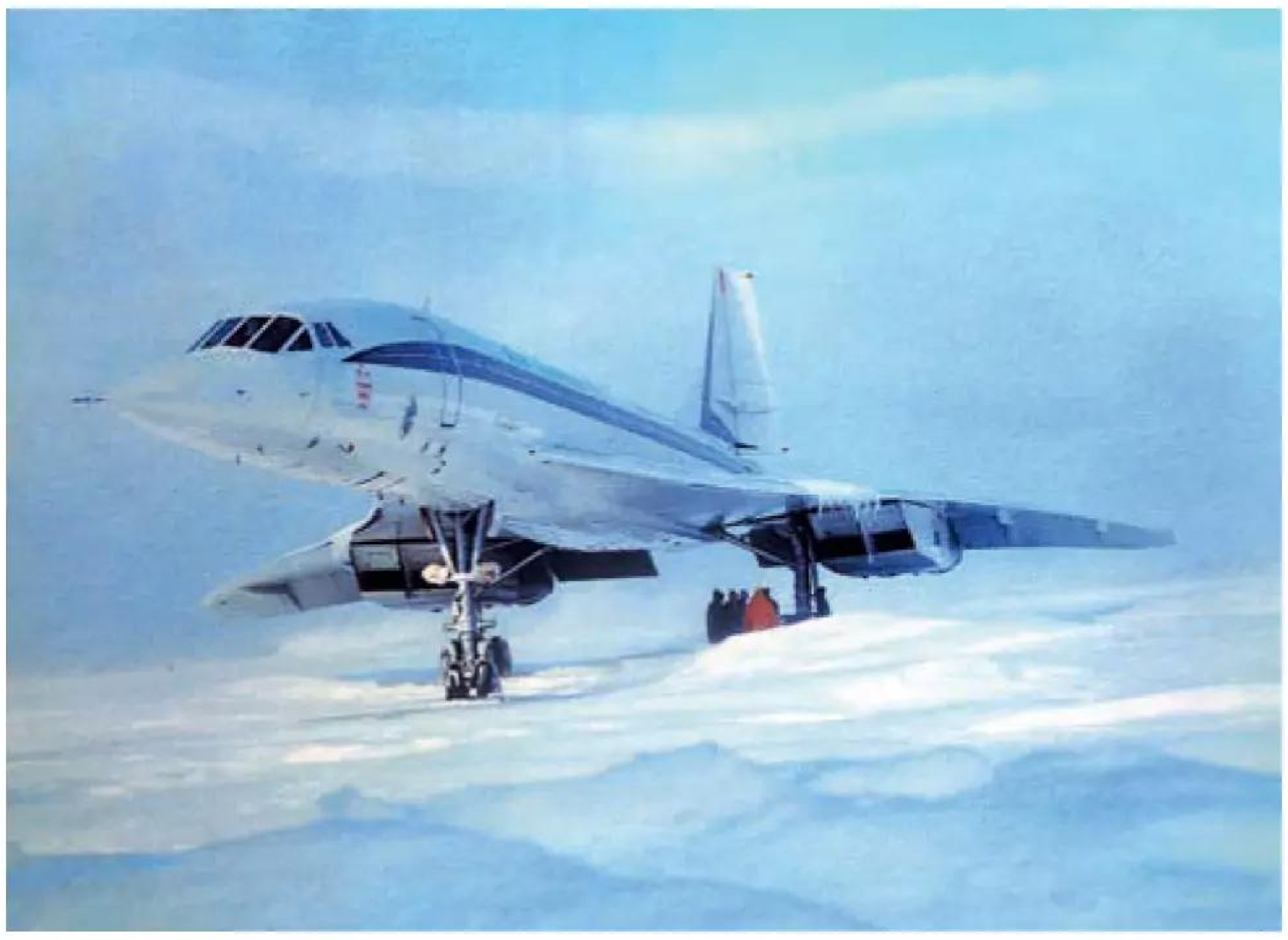
A final approach was made on three engines, with a normal full stop landing using four reversers and the brakes. These pilots summed up their general impressions in the report saying "for all the flight conditions flown during this first phase the aircraft was pleasant and easy to fly, imposed no excessive workload on the pilot even in failure conditions, and there should be no problems in training airline pilots and engineers to handle the aircraft." However, the instrumentation was criticized, most notably the Mach counter! Globally the use of 'tape' type instruments met with disapproval, and in terms of readability the use of 'clock' type instrument was preferred.

Returning to the test programme, at this stage the aircraft has been flown to Mach 1.3 with and without autostabilisers and with simulated engine failure. The handling characteristics were very good but a predicted deterioration in handling was present without auto-stabilisation, and was most noticeable without yaw stabilisation. With fuel transfer used between Mach 0.75 and 0.9 to move the centre of gravity back to 57% there was no difficulty with longitudinal trim changes, whilst both accelerating to Mach 1.2 and manoeuvrability appeared adequate since 45° banked turns had been maintained without loss of speed.

There had been no difficulty in controlling the aircraft following simulated engine failure, indeed the effects on aircraft control were hardly noticeable at all at Mach 1.2, and in general the pilots were particularly impressed by the smoothness and quietness of flight at supersonic speeds.

The limited flutter clearance needed for development flying was also now complete for the critical speed range between Mach 0.8 to 1.05, where flutter problems were most likely to occur, while the remaining three test points required to obtain flutter clearance to Mach 1.35 were expected to be obtained before 001 was grounded for modifications to the control system. 002 would now only have four flutter points to clear to extend the flight envelope to Mach 2 and it was most unlikely that flutter problems would delay the critical performance measurements at Mach 2.

On 29 November 1969 001 took Valery Giscard d'Estaing, the then French Finance Minister, on a demonstration flight. It appears that Giscard d'Estaing was the first 'civilian' outside the project team to fly aboard Concorde and, according to Turcat, he was "not enthusiastic" about the high-expenditure Concorde project. Other VIP passengers to sample Concorde during the flight test phase included French President Georges Pompidou, British Royalty in the form of Prince Charles and Princess Margaret, and British Prime Minister Edward Heath. In July 1973 French Prime Minister Pierre Messmer flew in pre-production Concorde F-WTSA.



Concorde 001 during cold weather trials at Gander. The variable-position ramps are visible inside the entrances to the intakes. *Sud Aviation via JC Carbonel*

At the start of December, the flight envelope had been extended to Mach 1.4 at 46,000ft (14,020m) and the take-off weight increased to 311,100lb (141,115kg), and by 22 December the maximum speed had been increased to Mach 1.5.

Sonic boom measurements had been taken with the help of the CEV with runs being made at various heights over Istres. When the 100th Concorde flight was reached (with only 24 made by 002 which was still undergoing modification) a speed of 1,000mph (1,609km/h) had been achieved, and by now the prototypes had flown a block time of 176 hours 35 minutes. The minimum airborne speed had been 127 knots (235km/h).

Prototype 002 finally made its first supersonic flight on 25 March 1970. Then in September of that year came the Farnborough Air Show at which 002 was displayed and which also provided an illustration of the potential for 'noise' problems when it had entered service. Taking off from its Fairford base on 13 September for its final appearance at that year's show the pilot, Trubshaw, found that the weather conditions were poor, with low cloud and visibility at Fairford limited to 2,500 yards (2,285m), and he decided almost at once to land at Heathrow rather than return to Fairford. This he did after appearing at Farnborough as planned, and 002 returned to Fairford the following morning.

Head on view of Concorde 001/F-WTSS, while in the background 002/G-BSST flies overhead with its undercarriage down. *BAE SYSTEMS Heritage, Farnborough*

However, the landing at Heathrow was widely reported in the press, as was the fact that numerous complaints were made about Concorde's noise (the British Airports Authority received about 50). Although no measurements were available (there were no restrictions on approach noise at Heathrow) there was no doubt that the noise levels produced by Concorde on this occasion were high both by comparison with commercial aircraft landing at Heathrow, and by comparison with the noise Concorde was likely to make when it entered airline service.

002/G-BSST made two spectacular passes at the Finningley Air Show on 16 September 1972. *The late Peter Green*

The bi-annual Farnborough and Paris Shows were important events to show Concorde off to the public. Prototype 002 comes into land at Farnborough.

In response to press enquiries, BAC pointed out that the aircraft had approached Heathrow flying unusually low because of the low cloud base; had still been heavily loaded with fuel, requiring greater engine power; had lowered the undercarriage early to increase drag and help burn off fuel, again requiring more engine power, and lastly, was a prototype fitted with development engines that were not silenced to in-service standards.

Both BAC and the British Airports Authority expressed their regret for the disturbance this incident had caused, but one encouraging aspect was that BAA reported that the next day's take-off proved to be no noisier than existing aircraft and they had received just one complaint.

Less than two months later, on 4 November 1970, came another major landmark – the first flight at Mach 2. Initially it had been agreed between Turcat and Trubshaw that, since 001/F-WTSS had done both 'first flight of type' and 'first flight at Mach 1', it would be the British team aboard 002/G-BSST who would have the honour of doing the 'first flight at Mach 2'. However, after some failed attempts (an oil leak when flying at Mach 1.35 had made it necessary to terminate 002's flight), Turcat was contacted and told to have a go, and he was successful. In fact, 001 maintained this speed for 53 minutes.

On 12 November, with the oil leak cured, 002 was able to reach Mach 2 after a long acceleration along the English east coast. Then, at an indicated Mach 2.02, Trubshaw reduced power gently which triggered a ferocious port side double engine surge (this in fact happened twice), Trubshaw later commenting that he "thought World War Three had broken out". As engine power had been reduced, 002 had dipped its nose slightly which enabled the wake from the leading edge of the wing to be ingested by the engines.

The leading edge was subsequently redesigned to incorporate increased camber but, prior to this, the -3B engines would continue to experience surging. In fact the -3Bs presented a problem because they were short of thrust. This meant reheat had to be used to achieve high Mach numbers, the aircraft would accelerate slowly and, because Mach number is affected by ambient temperature, on occasion the prototypes would not quite reach Mach 2.

The 100th supersonic flight was recorded in January 1971. However, on 26 January an incident occurred in flight which resulted in 001 being grounded for some weeks, but it also demonstrated just what a tough item the Olympus engine was. The aircraft, which was flying out of Toulouse for the second time since a recent lay up, was engaged in deliberate surge testing at Mach 2. When flying at Mach 2 and 50,000ft (15,240m) No. 3 engine was cancelled, it surged and then No. 4 suffered an interactive surge, the aircraft experiencing (as one might imagine) considerable vibration.

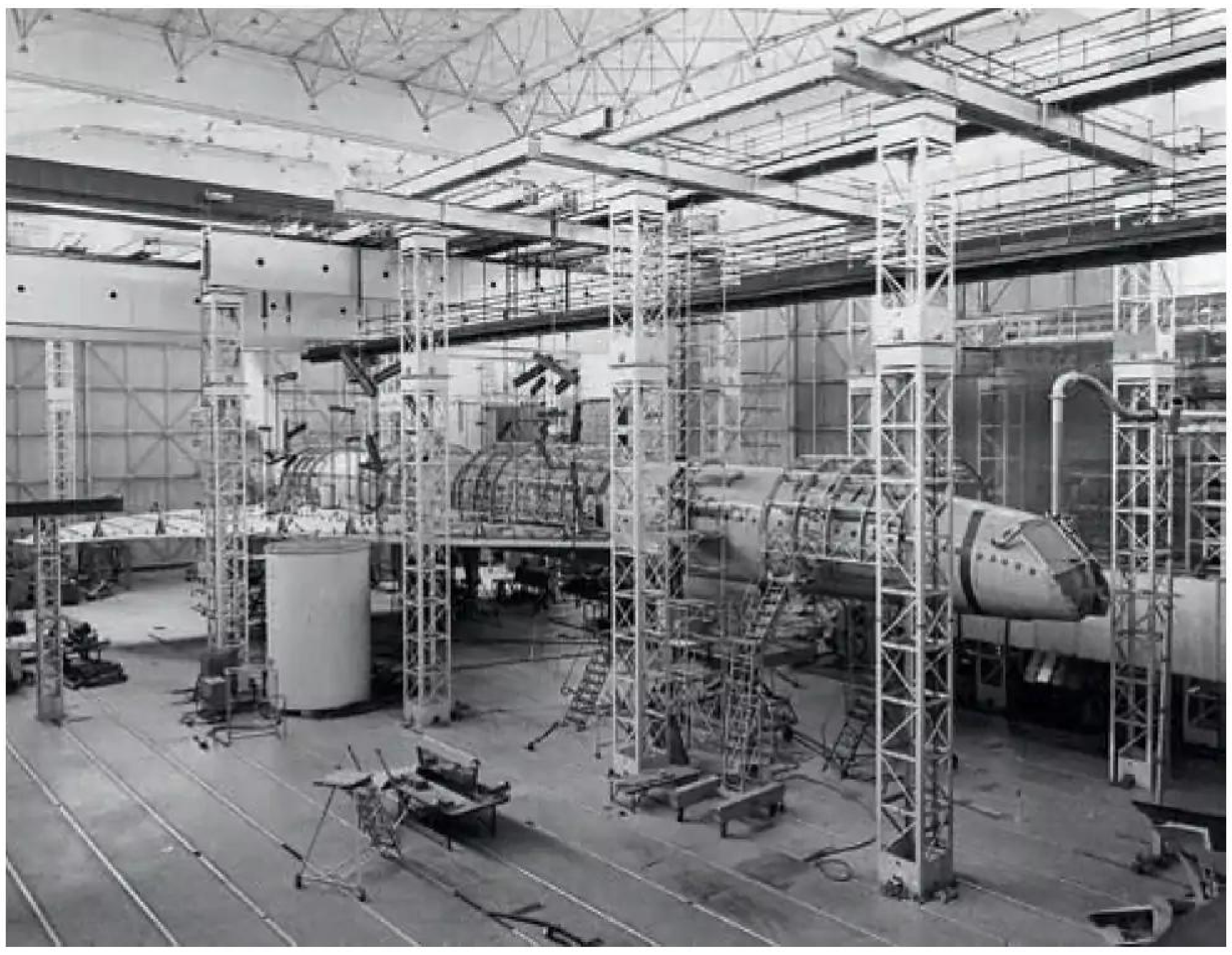
Speed was reduced to Mach 1.2 and No. 4 was then relit but, though running at 90% rpm, it ran so roughly that it was closed down completely. Using the underfloor periscope the crew found that the forward ramp in the intake of no. 4 engine had in fact disappeared, so the aircraft returned to base on three engines and made a safe landing. An inspection on the ground showed that the forward ramp had broken away and had moved forwards and backwards under the nacelle, hitting and damaging the underside of the intake. Some fragments had also gone into the engine which had been heavily damaged and was removed (although it still ran!). Incidentally, looking at the aircraft's performance on less than four engines, former test pilot Clive Rustin told the author that he once did a flight with Trubshaw in which two engines were shut down – and it still flew at Mach 1.35!

The two Concorde prototypes went on to complete impressive careers and proved to be extremely valuable machines. On 19 October 1973 001/F-WTSS landed at Le Bourget airport on its last flight and was then towed to its new home in the Musée de l'Air et de l'Espace, where it has resided ever since. In all 001 completed 397 flights totalling 812 hours flying time with 255 hours at supersonic speed.

The last flight for 002/G-BSST was on 4 March 1976 when the aircraft was flown to the Fleet Air Arm Museum at Yeovilton, where today it is displayed with the Handley Page HP.115 and BAC.221. Prototype 002's career embraced 438 flights (196 supersonic) for a total of 836 hours in the air.

PRE-PRODUCTION AIRFRAMES

As Concorde's development progressed, three different versions would ultimately be built. The first was represented by the two prototypes 001 and 002 above which could not be classed as long-range supersonic transports, but they were of course vital for proving the design in flight. Changes to the design for the next stage, two pre-production machines (serials 101 and 102, or 01 and 02), included a modified wing planform, more fuel, a different standard of engine, and a revised air intake system. The final production machines



This Concorde static test airframe, one of two, was set up at CEAT, the Centre d'Essais Aéronautiques (Aeronautical Testing Centre) in Toulouse. *Richard Curtis*

On 6 January 1972 the three Concordes currently participating in the flight development programme were photographed together for the first time at BAC's Flight Test Centre at Fairford. The previous day the French-assembled 001 had flown from Toulouse to Fairford to participate in calibration tests along the West Coast route. Late on the 6th 001 returned to Toulouse after making a satisfactory flight at twice the speed of sound along the supersonic test corridor. The aircraft lined up on the tarmac at Fairford are British prototype 002/G-BSST, British pre-production 01/G-AXND and French prototype 001/F-WTSS. *BAE SYSTEMS Heritage, Farnborough and Richard Curtis*

(serials 201 to 216) proved to be different in many ways to the original prototypes and in certain areas this necessitated a re-examination to obtain certification.

Before looking at 01 and 02 it should be noted that two further complete full-sized airframes were set aside for an exhaustive programme of ground-based static and fatigue testing. One of these was based at the Royal Aircraft Establishment at Farnborough and was subjected continuously to the complete range of loads, stresses and changes of temperature experienced during supersonic flights. The objective was to ensure that this airframe had always completed more than three times the total flight hours of the first Concorde to enter airline service. The second ground test Concorde was based in France and the go-ahead for the construction of this pair of static-test airframes was given in 1970.

The first pre-production aircraft 01 was registered G-AXDN and built at Filton, the second, 02, received the serial F-WTSA and was turned out at Toulouse. 01/G-AXDN featured the production standard clear glass cockpit visor and an increased maximum take-off weight. However, despite these major differences, 01 was something of a hybrid because it had not been completed to full pre-production standards. It was also fitted with Olympus 593-4 engines with which made its maiden flight on 17 December 1971, again a journey from Filton to the Fairford test base.

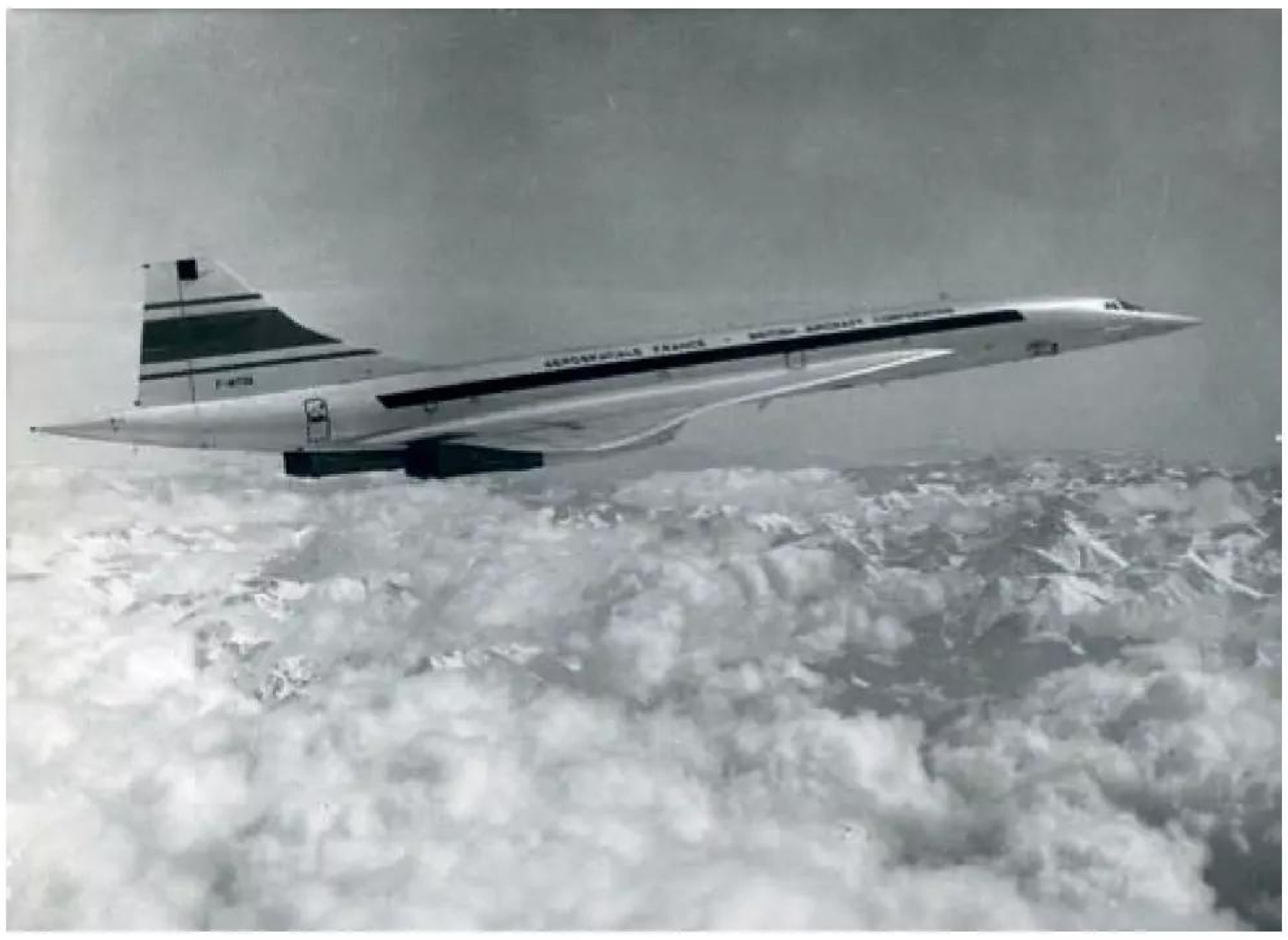
Only four days later, on 21 December, it proved possible to have all three flying Concordes in the air simultaneously. 01 went back to Filton in August 1972 to receive Olympus 602 engines and other modifications which brought the aircraft up to full standard. It then made a number of 'show the people' flights around various parts of the UK.

During 1974, 01/G-AXDN visited Tangier twice (in February and April) to continue trials into the functioning of the variable geometry air intakes at low temperatures and high altitudes. The prototypes had revealed difficulties in matching the intakes and the engines, a vital matter since supersonic airliners were to spend the majority of their flying time at the limits of their performance. They needed to operate at the greatest possible efficiency, and their engines had to run as close as possible to the surge boundary (a problem about which Mach 2 aircraft in military service did not have to worry). This very important phase of the flight test programme was to be concluded happily and successfully.

To demonstrate, on 14 April 1974 01/G-AXDN recorded a speed of Mach 2.23 during its 170th flight, in the process giving this aircraft the distinction of flying faster than any other Concorde during the trials in which it was involved, and later in the same flight it reached an altitude of 63,700ft (19,416m). What was most important, however, was that while flying at this speed 01 was manoeuvred gently so as to induce small incidence and sideslip angles, to establish that this could now be done without causing an engine to surge. To illustrate just how important this intake and engine matching effort had been, out of Concorde 01's first 188 flights exactly 100 were flown in direct support of this programme of intake refinement.

Then on 7 November 1974 01, flown by BAC deputy chief test pilot John Cochrane, recorded the fastest ever civil crossing of the North Atlantic in a westerly direction (wheels-off to wheels-on), covering the 3,270 miles (5,261km) between Fairford and Bangor in Maine, on the US Coast, in just 2 hours and 55 minutes. Concorde 02 had set the previous fastest time in June 1974 with a flight from Paris to Boston in 3 hours and 8 minutes, while a record established by a Lockheed SR-71 reconnaissance aircraft the previous September had been set between 'radar gates' at altitude.

The first two French Concordes, prototype F-WTSS and pre-production F-WTSA, are seen together at Toulouse.



F-WTSA pictured during an early flight.

During the Fairford to Bangor trip, 01 flew at supersonic speed for 2 hours and 30 minutes, at Mach 2 for 2 hours and 9 minutes, and it reached a maximum of Mach 2.07 at 55,000ft (16,764m). The purpose behind this journey, during which after a refuel 01 continued across America at subsonic speed, was to spend some weeks at Grant County Airport at Moses Lake in Washington State to undertake trials flying in natural icing conditions. This was in order to obtain icing clearance for the American and British authorities. After a relatively short career comprising 269 flights with 168 of them supersonic, and a total flight time of 632 hours, 01/G-AXDN was retired. On 20 August 1977 it was flown to the Imperial War Museum at Duxford, where it remains.

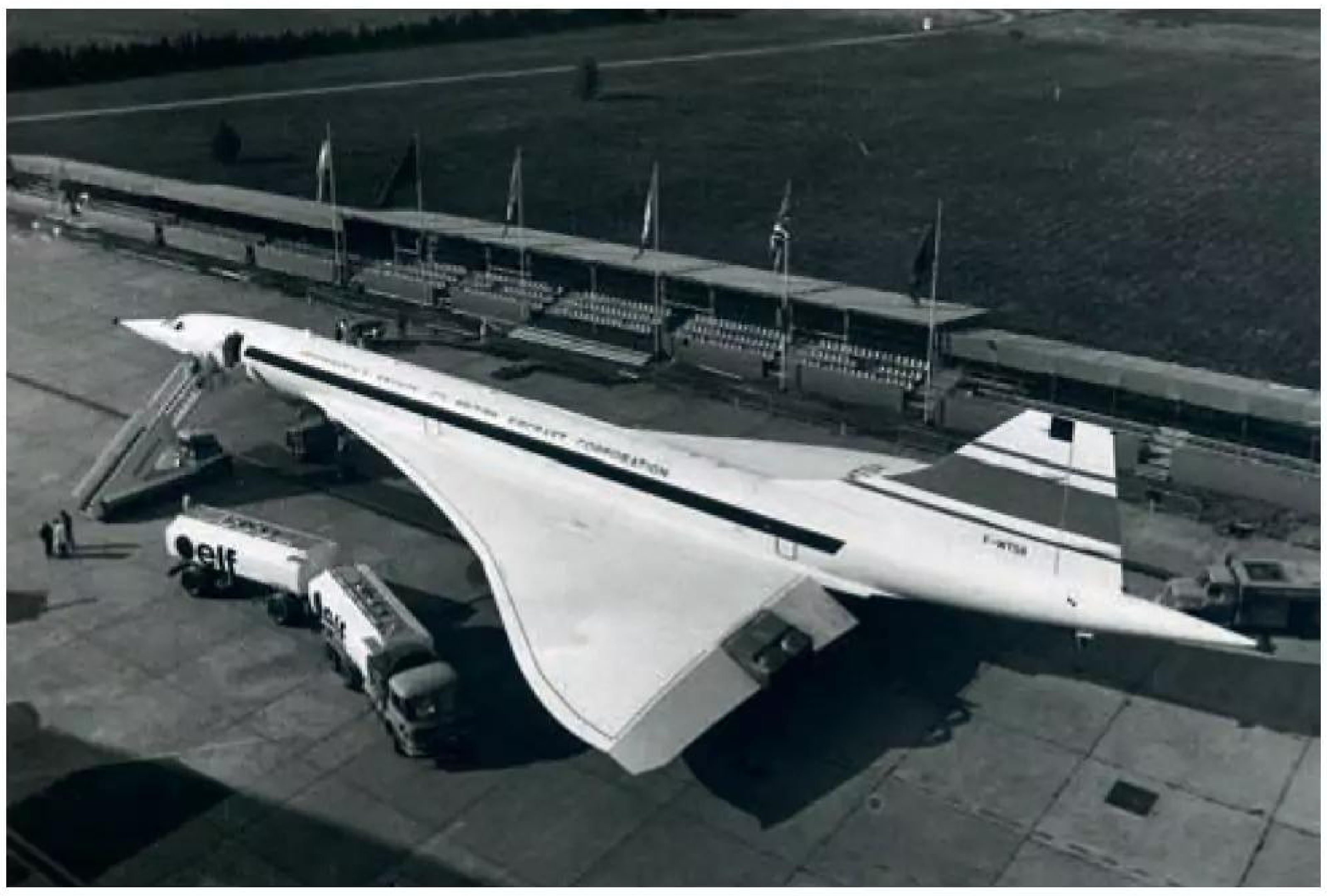
The second pre-series aircraft 02/F-WTSA made its maiden flight on 10 January 1973 with Olympus Mk.602 engines already installed. The pilot on this occasion was Jean Franchi and Jean Pinet was his co-pilot. This aircraft introduced an extension to the end fuselage tailcone of 2.59m (8ft 6in) which had been prepared for production aircraft to provide a reduction in drag. During that year's Paris Air Show, between 24 May and 3 June, 02 performed demonstration flights for important officials and personalities. After such a flight, Barry Goldwater, the US presidential envoy at the show, said: "Whether we want it or not, when the first supersonic aircraft will land in the USA, be it Anglo-French or Russian, the demands to fly aboard it will stupefy the US Airlines."

It was in fact 02 that made the Concorde's first visit to the United States, in September 1973. It left Paris Orly on the 18th piloted by Franchi to attend the official opening of Dallas Fort Worth Airport, making a stop at Las Palmas during its outbound crossing over the south Atlantic before landing at Caracas, where it flew a demonstration flight. The subsequent trip to Dallas with 32 passengers on board, most of them important dignitaries with government or different airlines, included a supersonic over-water leg.

More significantly, however, the return journey to Paris was made via Washington so as to make the first ever Concorde crossing of the North Atlantic, and at Mach 2. At Dallas on 22 September 02 had participated as the star attraction in an air show which had opened the new airport. For this trip, and retained for some time afterwards, 02/F-WTSA had been painted in Air France colours on its port side and in British Airways colours on its starboard side.

Further demonstration flights followed during 1974, although from 2-19 February the aircraft was used in cold weather trials out of Fairbanks in Alaska having flown there via Keflavik Airport in Iceland. In June, to climax a set of reliability and route proving trials, 02 made a 12,000-mile (19,308km) round trip from Paris to Rio de Janeiro in just 12 hours 47 minutes. And then to make an even stronger point, on 17 June it departed from Boston in Massachusetts just as a Boeing 747 bound for Boston was taking off from Paris.

The Concorde flew to Paris, completed a normal turn-around, and then took off and flew back to Boston to arrive ahead of the 747. Finally, during October, 02 flew an American Pacific Coast tour, in the process visiting London, Gander, Mexico City, San Francisco, Anchorage, Los Angeles, Bogota, Caracas, Las Palmas and Paris. Besides their contribution to the development programme, these overseas demonstration flights showed that the



Here 02/F-WTSA displays Concorde's beautiful wing shape.

British airways

For its trip to Dallas in September 1973 02/F-WTSA was painted in Air France colours on its port side and in British Airways colours on its starboard side.

airliner could fit into the ordinary air traffic routine. In addition, new information was collected on the winds and temperature patterns found in the upper atmosphere, which was essential for the preparation of airline flights in excess of 50,000ft (15,240m). In fact during a test flight made in June 1973 Concorde flew to an altitude of 68,000ft (20,726m).

From 30 May 1975 02/F-WTSA was back on familiar territory performing demonstration flights at the Paris Air Show. On 20 May 1976 the second pre-production Concorde was finally retired to Orly Airport in Paris where it is still on public display. Altogether this aircraft accumulated 314 flights totalling 656 flight hours and 189 of these flights had included periods at supersonic speed.

The process of design, however, did not stop. Changes made to Concorde as a result of the trials flying for example included a reduced maximum nose-down angle, to 12.5° from the original 17.5°. And it was because of these changes, and the fact that three versions of Concorde had resulted, that the aeroplane entered service at a rather later date than had originally been intended. These modifications meant that certain tests had to be repeated several times (there were three flutter test programmes) which hampered and delayed the certification process. As an aside, to keep the British Concordes from being a noise nuisance during full performance trials flying, a supersonic cruise corridor was established along the British west coast, primarily over the Irish Sea but touching bits of land over Cornwall, Wales, Northern Ireland and Scotland. Concorde test flying also used 'supersonic' routes over the Bay of Biscay and the North Sea.

PRODUCTION AIRCRAFT

In April 1970 the go-ahead was given to start the first three production Concordes, numbers 201 to 203, this was followed in December by 204 to 206 and then in April 1971 by 207 to 210. Another six, numbers 211 to 216, were approved in 1971. The first of these, 201/F-WTSB, first flew from its Toulouse birthplace on 6 December 1973 and such was the confidence in the Concorde design now that it went supersonic on this first flight, reaching a maximum of Mach 1.57. On 13 February 1974 the first British production Concorde, 202/G-BBDG, made its maiden flight from Filton.

However, despite 201 and 202 being built to production standard with full passenger interiors and wearing airline liveries, in terms of certification they were regarded as a different aircraft and so neither ever entered airline service. In truth both 201 and 202 served as two further 'development' aircraft, making six Concordes in all used exclusively for development work out of the 20 actually built. These two were used for further route-proving and sales tours, 201/F-WTSB completing a total of 909 hours of flying before making its final flight on 19 April 1985. It is now preserved in the Aeroscopia Museum at Toulouse. 202/G-BBDG accumulated 1,282 hours in the air and flew for the last time on 24 December 1981. Today it is on display at the Brooklands Museum in Weybridge, Surrey.

The first full-standard production aircraft were 203/F-WTSC and 204/G-BOAC and for a period during 1975 they too were used for route-proving to the planned destinations of the first Concorde airline services and for certification testing. Certificates of Airworthiness for Concorde were awarded in France and Britain respectively on 9 October and 5 December 1975, after in total some 5,540 hours of flight testing. In all this embraced 2,480 flights, a figure which came to around four times the number of sorties that would have been needed to clear a subsonic aircraft of similar size.

The first Concorde delivered to an airline was 205/F-BVFA to Air France where it was accepted on 19 December 1975, while on 14 January 1976 206/G-BOAA became the first example to be delivered to British Airways. ◆

10

Orders and Into Service

Beautiful photograph showing production Concorde G-BOAG in the British Airways livery used during much of the 1980s and 1990s. *BAE SYSTEMS Heritage, Farnborough*

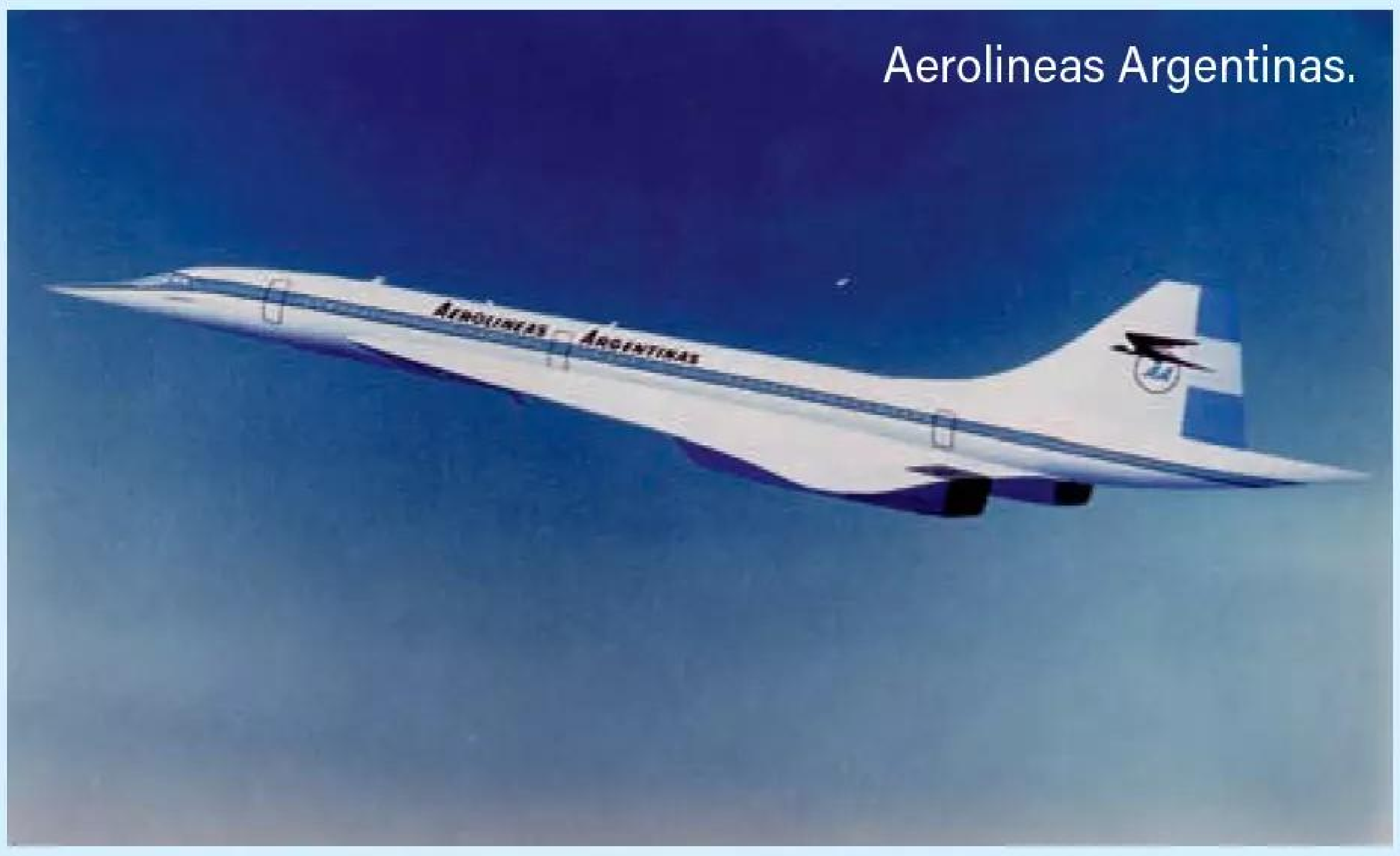
The SST bubble had begun to burst well into Concorde's test flying. It was becoming likely that the new supersonic airliner would only ever be accepted if it flew supersonically over water, there was a growing campaign against the aircraft in the USA, and then by the time it approached its first revenue-earning flights the price of oil had rocketed. Coupled with the way the cost of the aircraft itself had increased, any chance of making a clear profit from the programme evaporated. This part of the Concorde story has been well covered in past publications, so only a brief review is presented here to bring to an end to the story of the design and development of Concorde.

SALES DRIVE AND LOST 'ORDERS'

The sales effort mounted in support of Concorde seemed for a period to show that the world of aviation was ready to embrace the SST. Although BOAC (later British Airways) and Air France, the two national airlines, were involved from the start, it was in fact Pan American who became the 'launch customer' and the first of many foreign airlines to sign purchase agreements for Concorde, placing 'provisional orders' for six aircraft on 4 June 1963 (soon after this order was announced US President John F. Kennedy gave the go-ahead for the American SST programme).

By the time the Concorde prototype made its first flight the list of orders, or more accurately options, had reached 74 and involved 16 airlines. Besides Pan American the list comprised Air Canada, Air India, American Airlines, Braniff, CAAC (the Civil Aviation Administration of China), Continental, Iran Air, Japan Airlines, Lufthansa, Middle East Airlines, Olympic Airways, Panair do Brasil, Qantas, Singapore Airlines, TWA (Trans World Airlines) and United Airlines. In 1967 BAC's sales manager declared that, based on the most pessimistic assumptions, Concorde sales would reach 225 by 1975.

Air France.


Aerolineas Argentinas.
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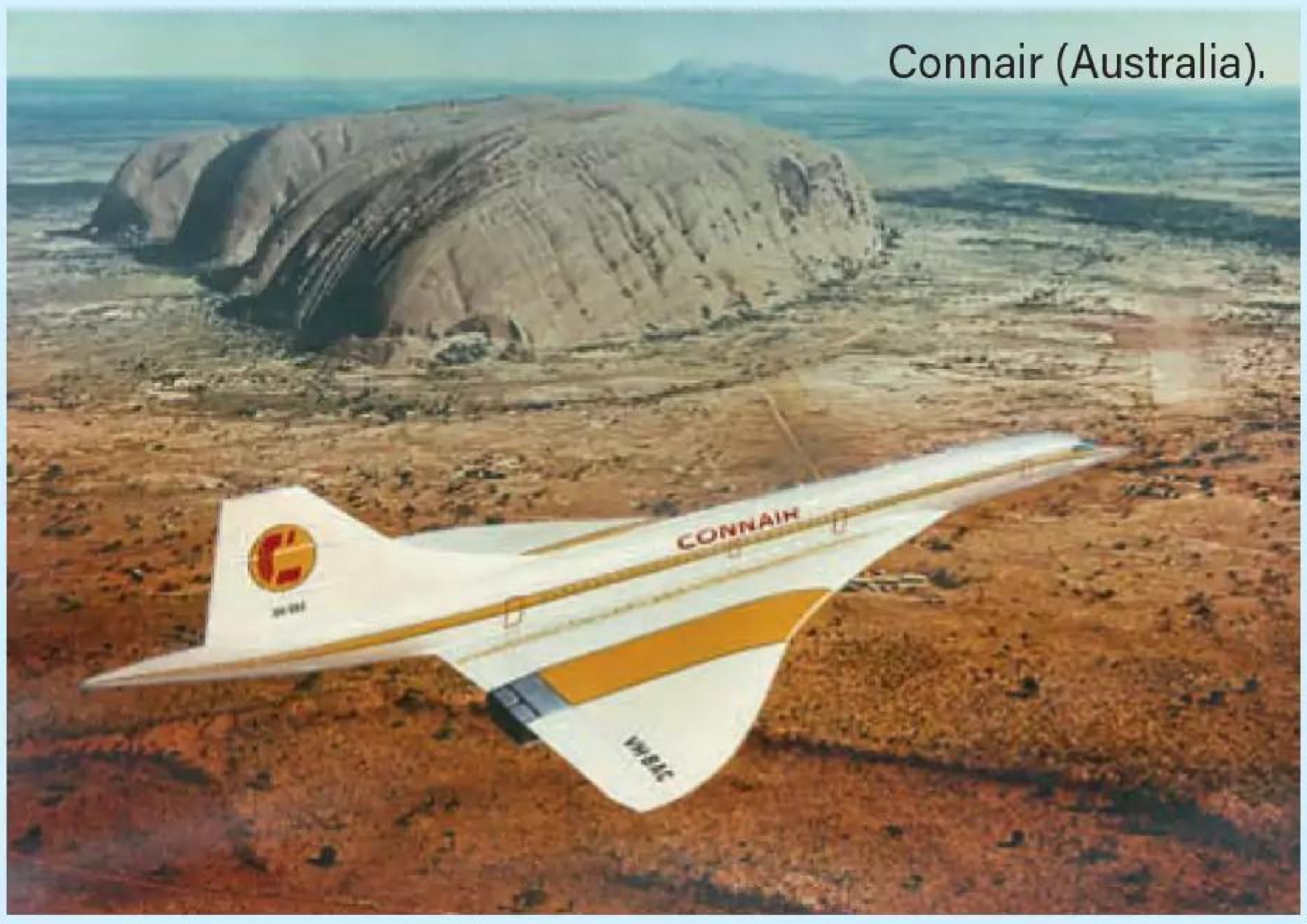
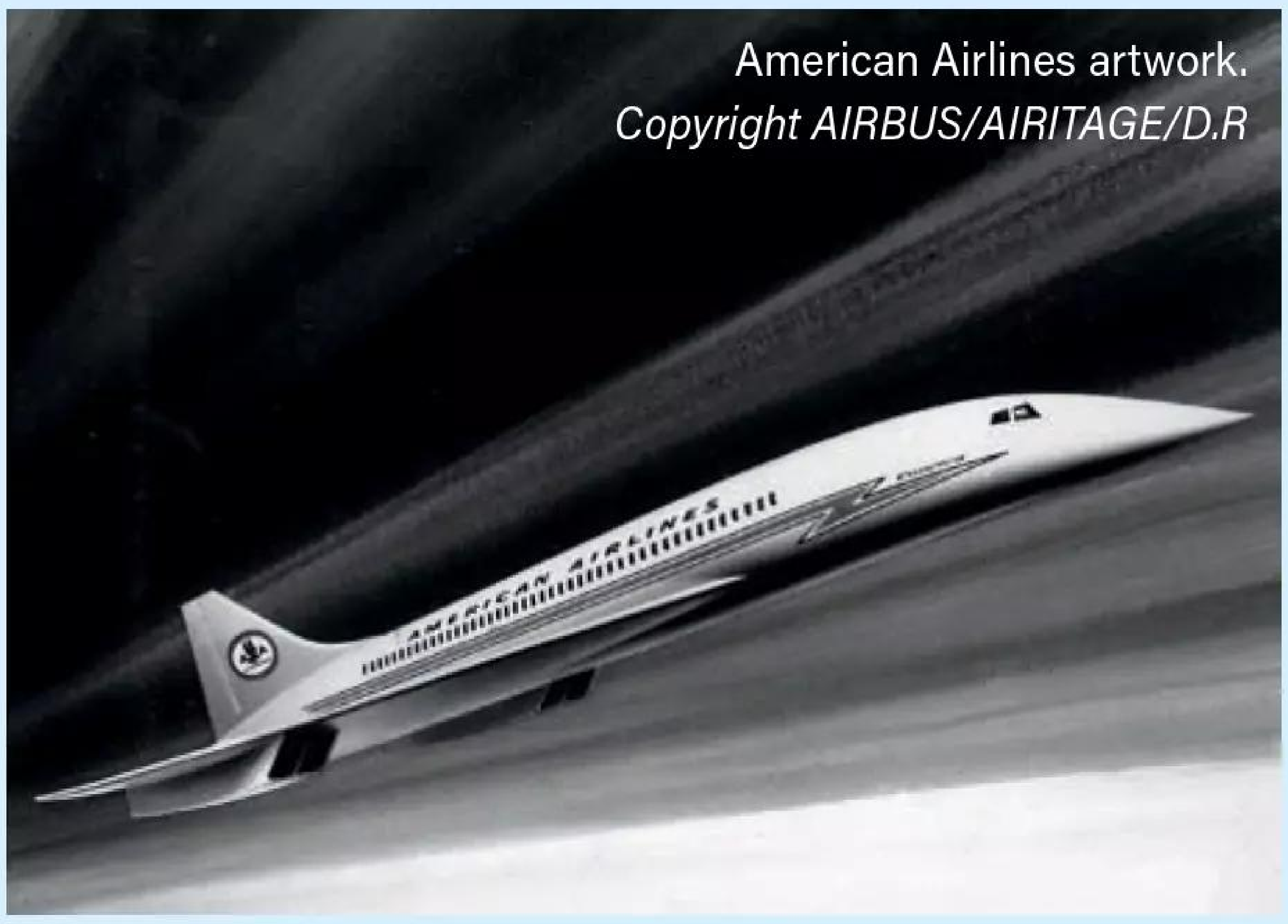
BOAC.

American Airlines.
AMERICAN AIRLINES


Connair (Australia).


American Airlines artwork.
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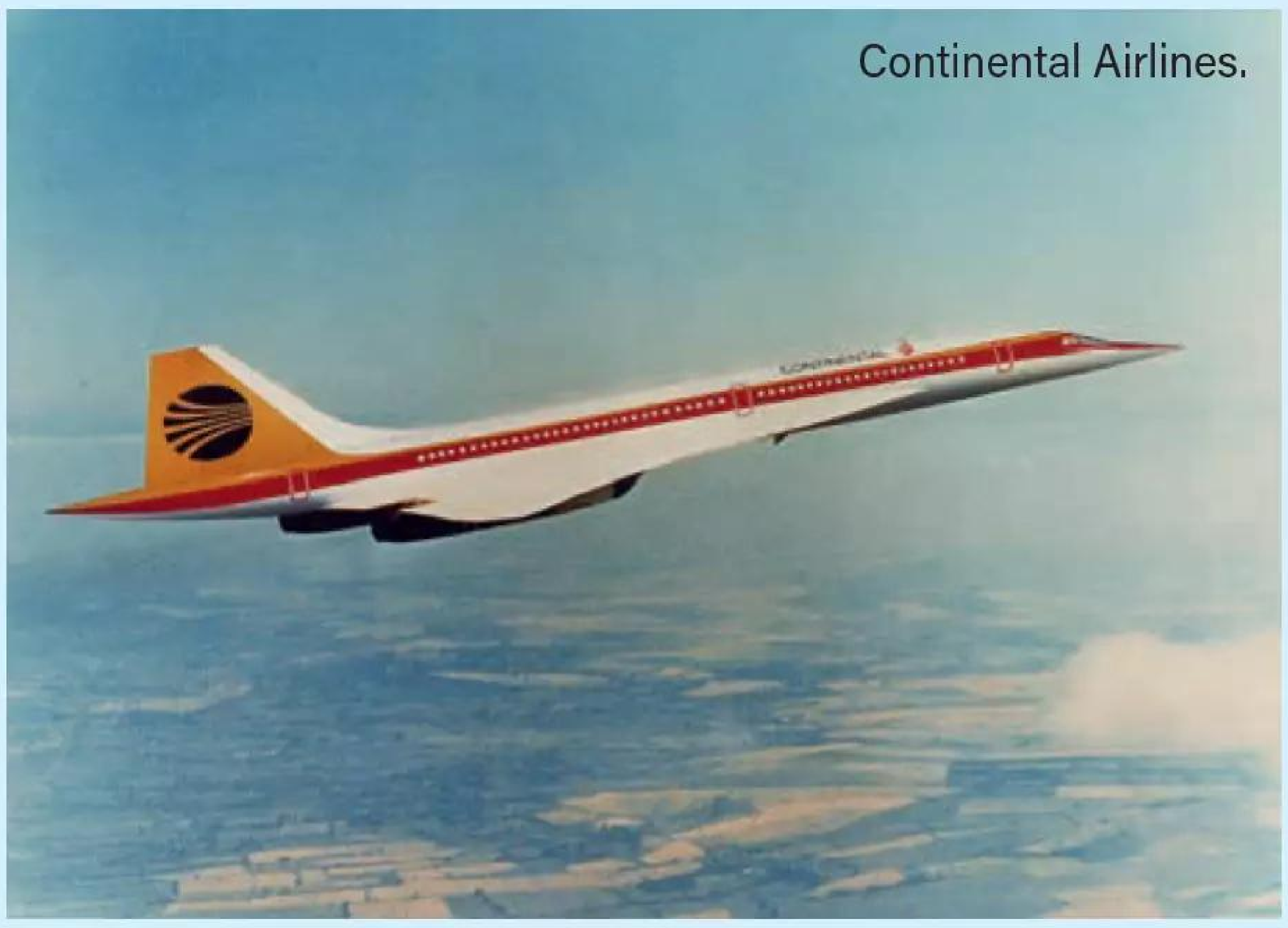
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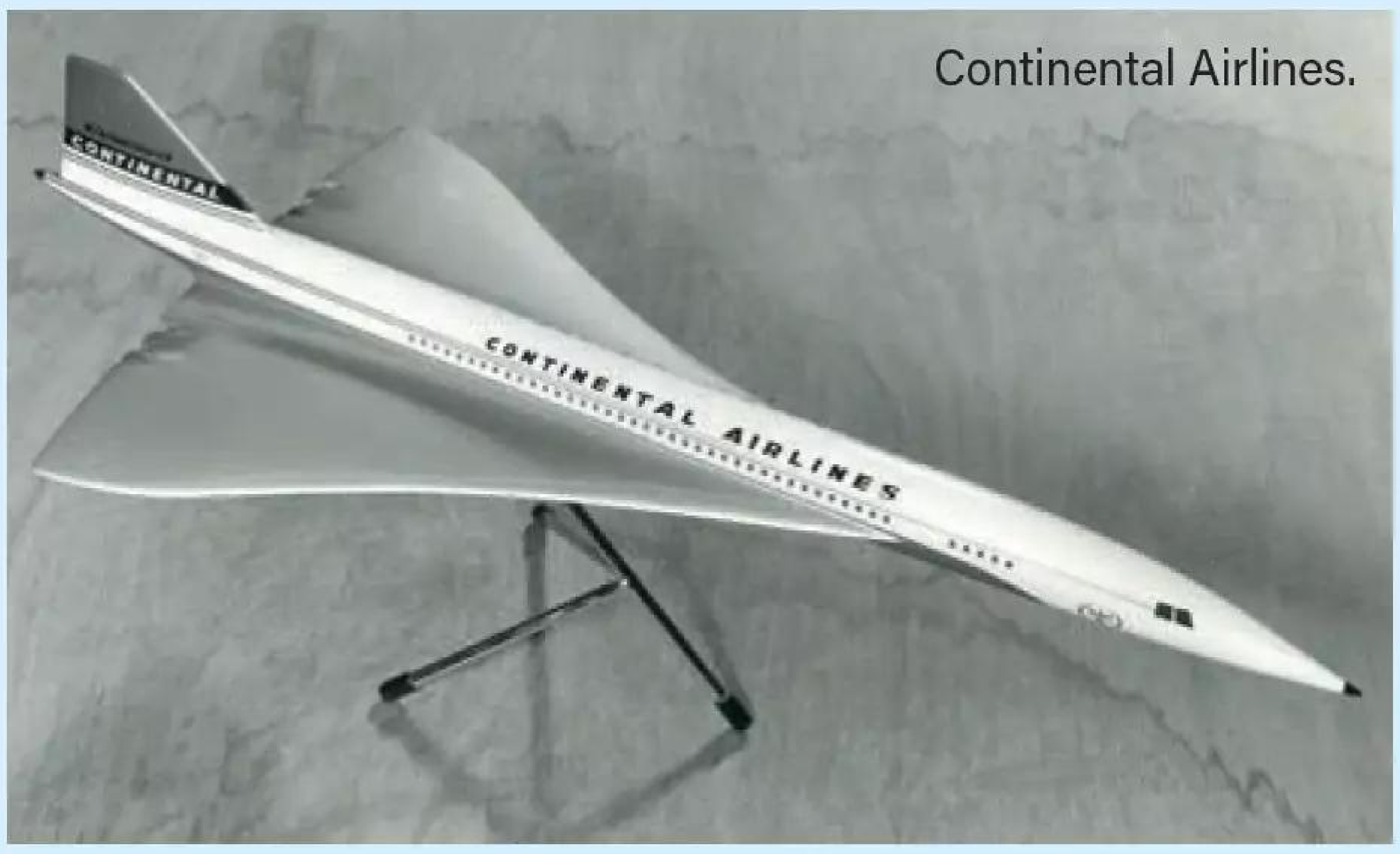
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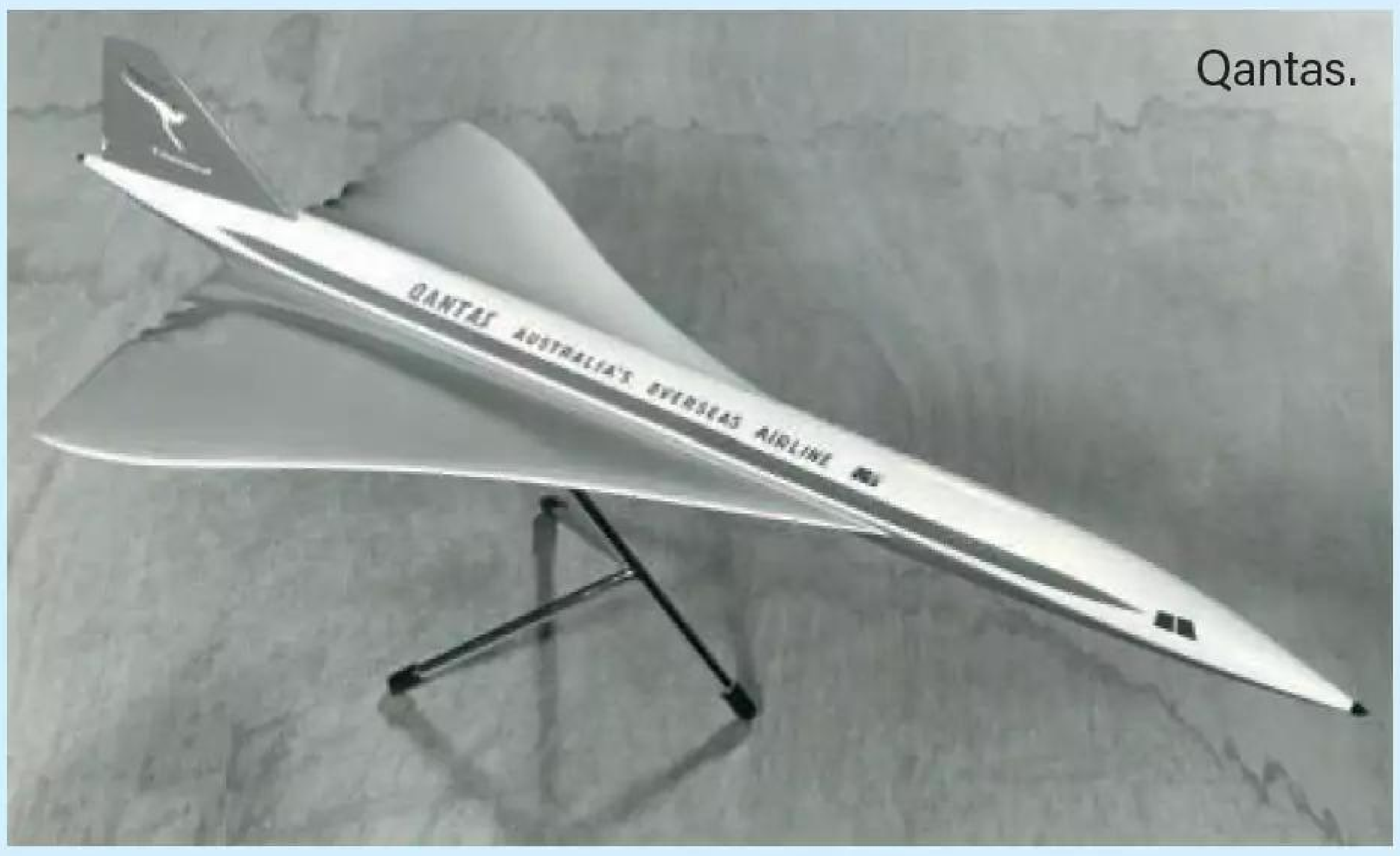
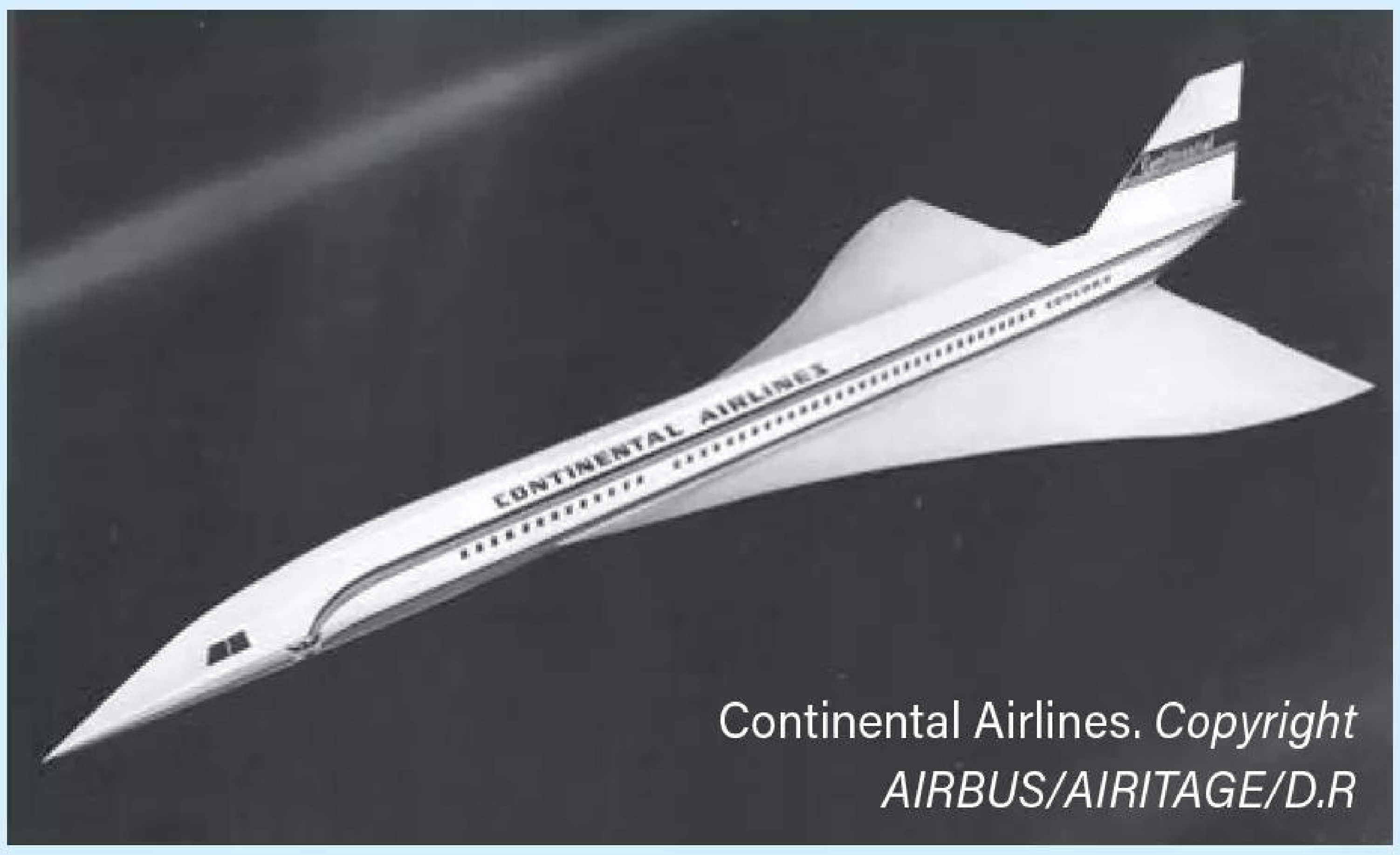
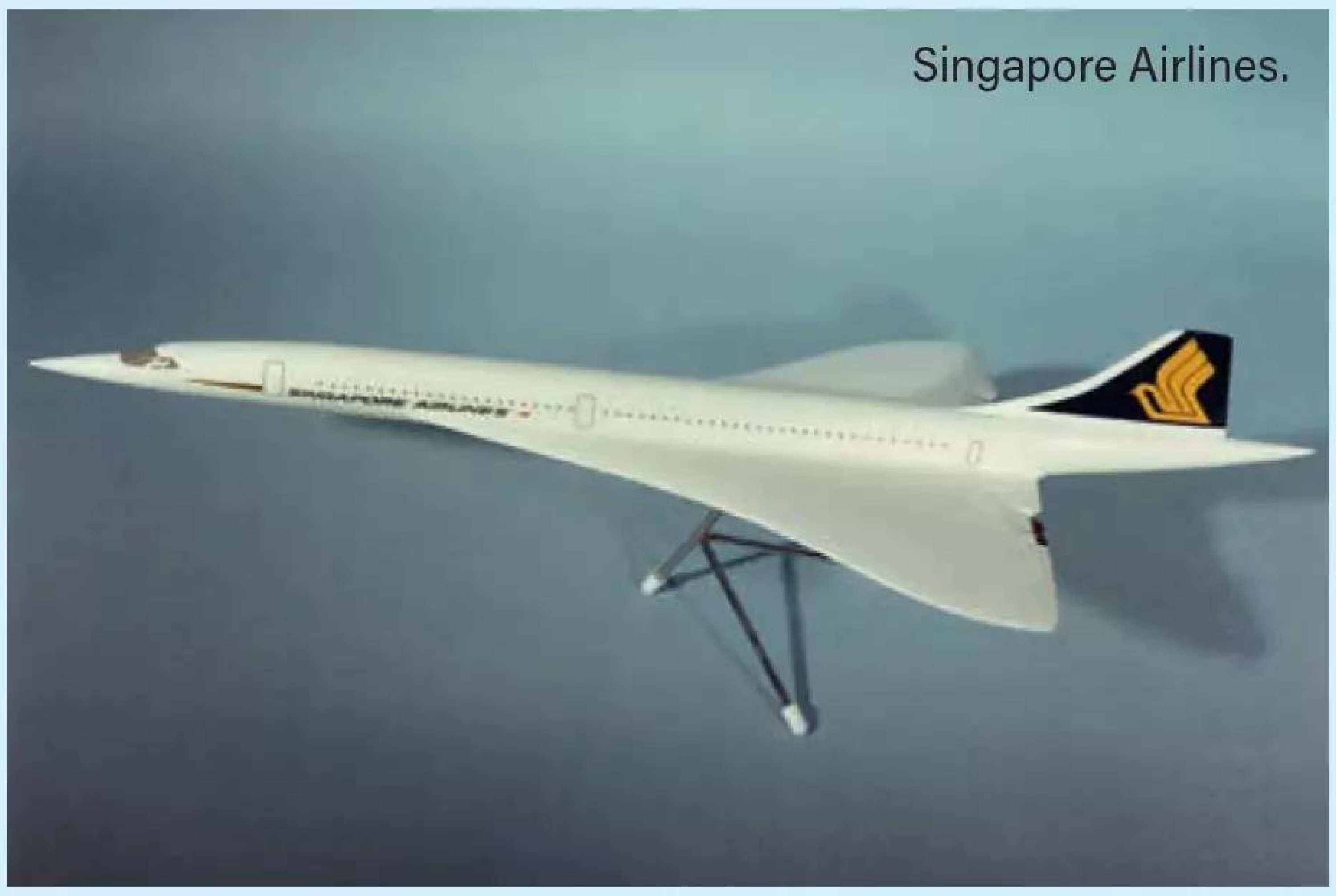
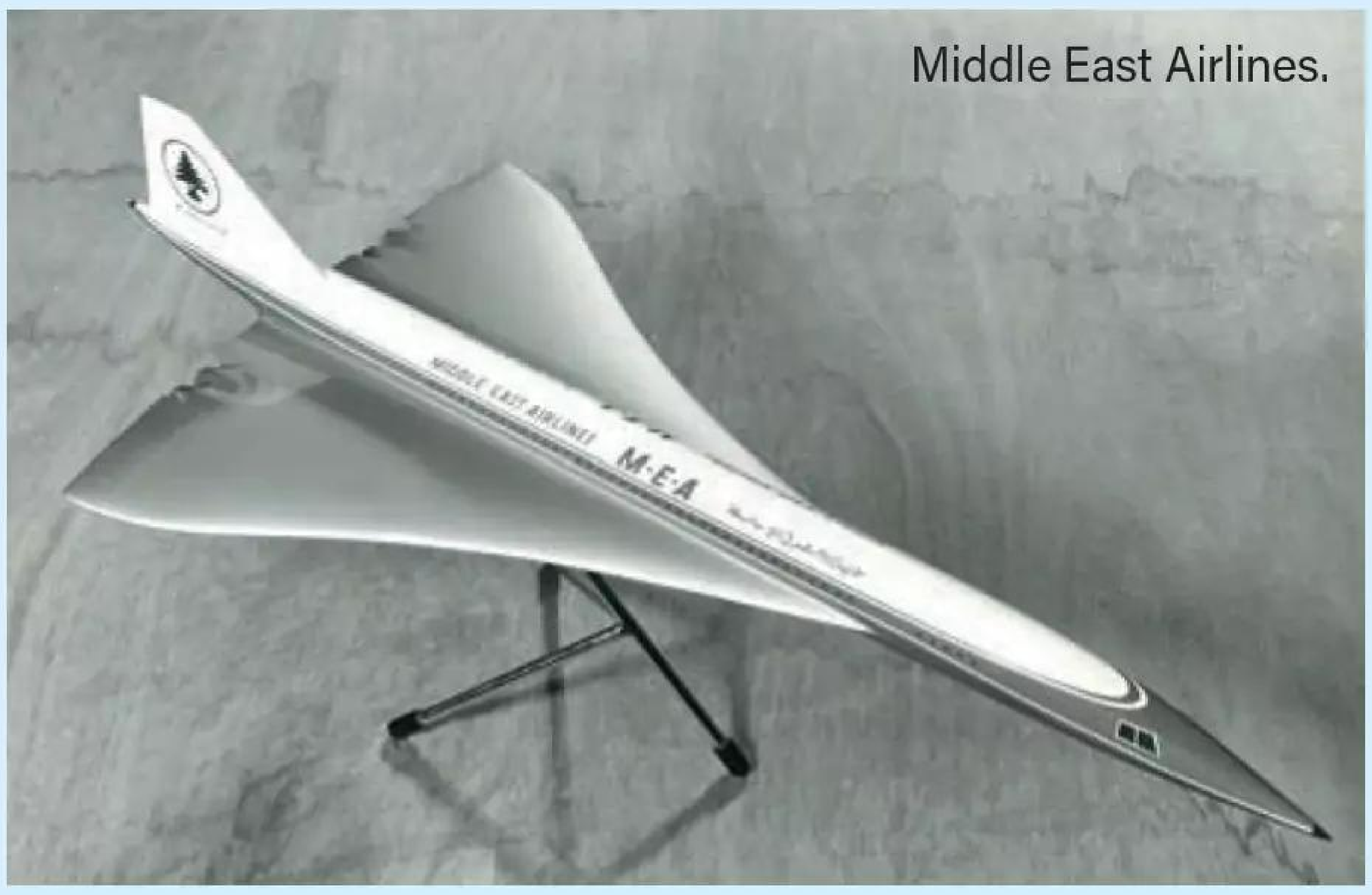
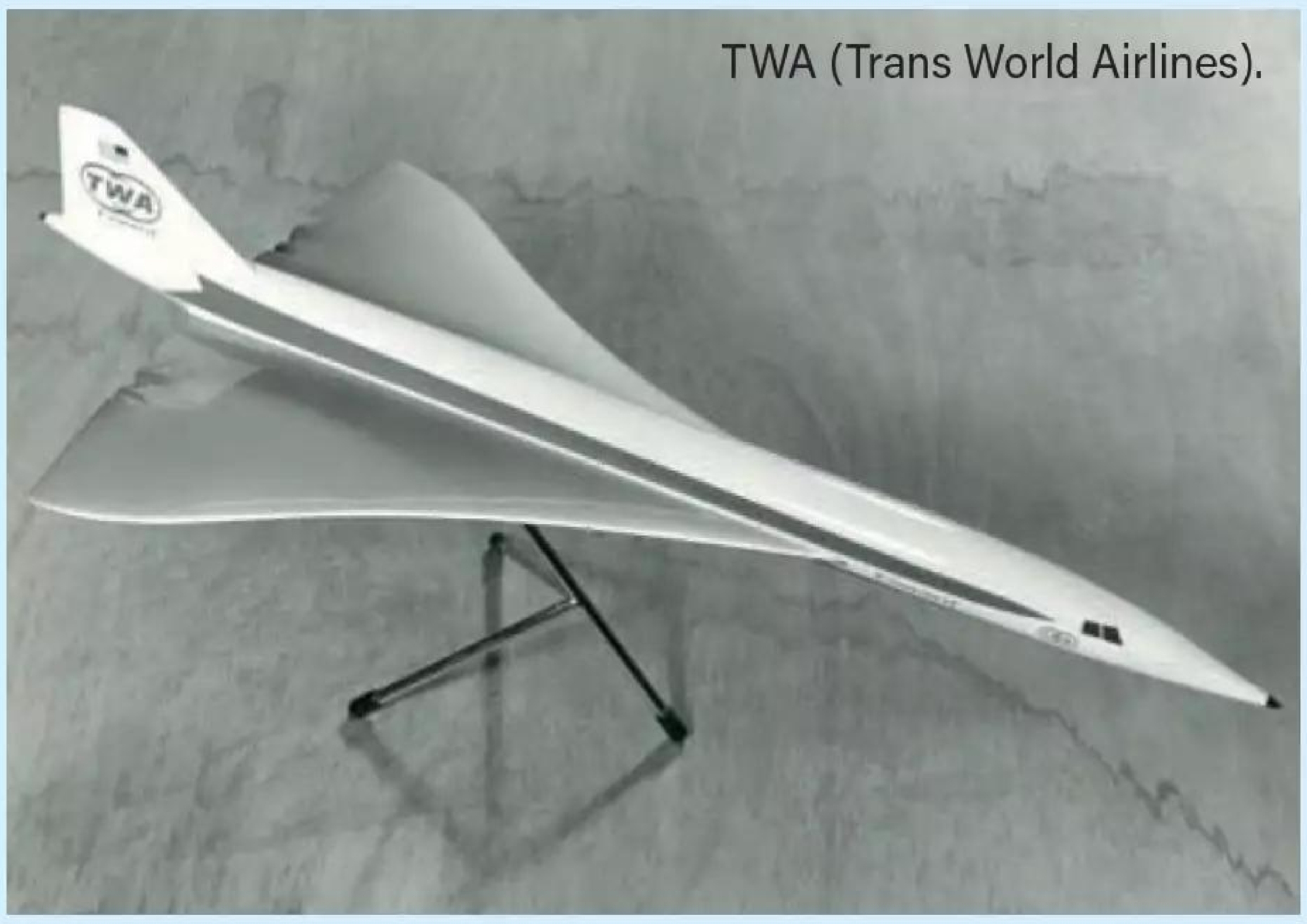
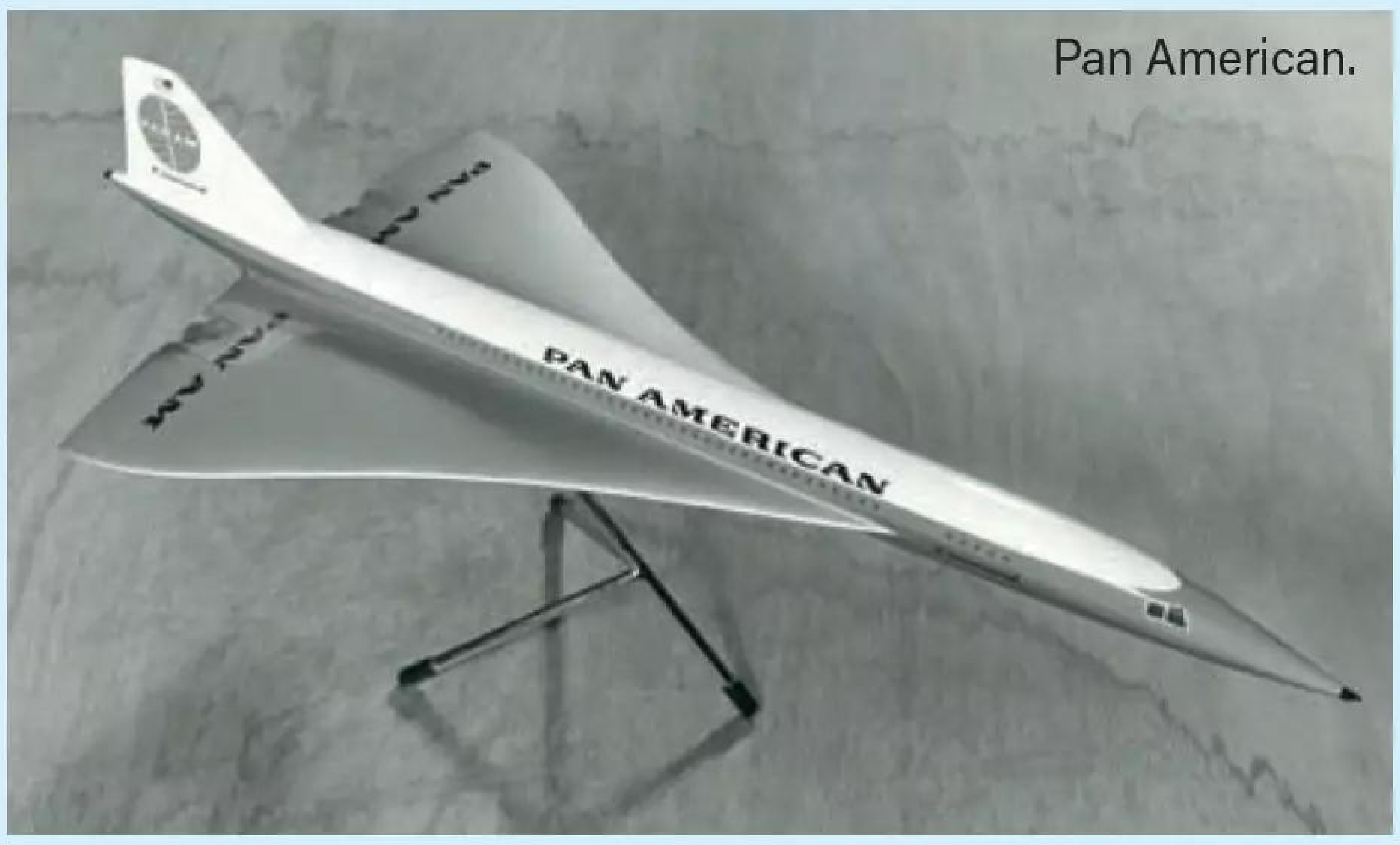

Qantas.

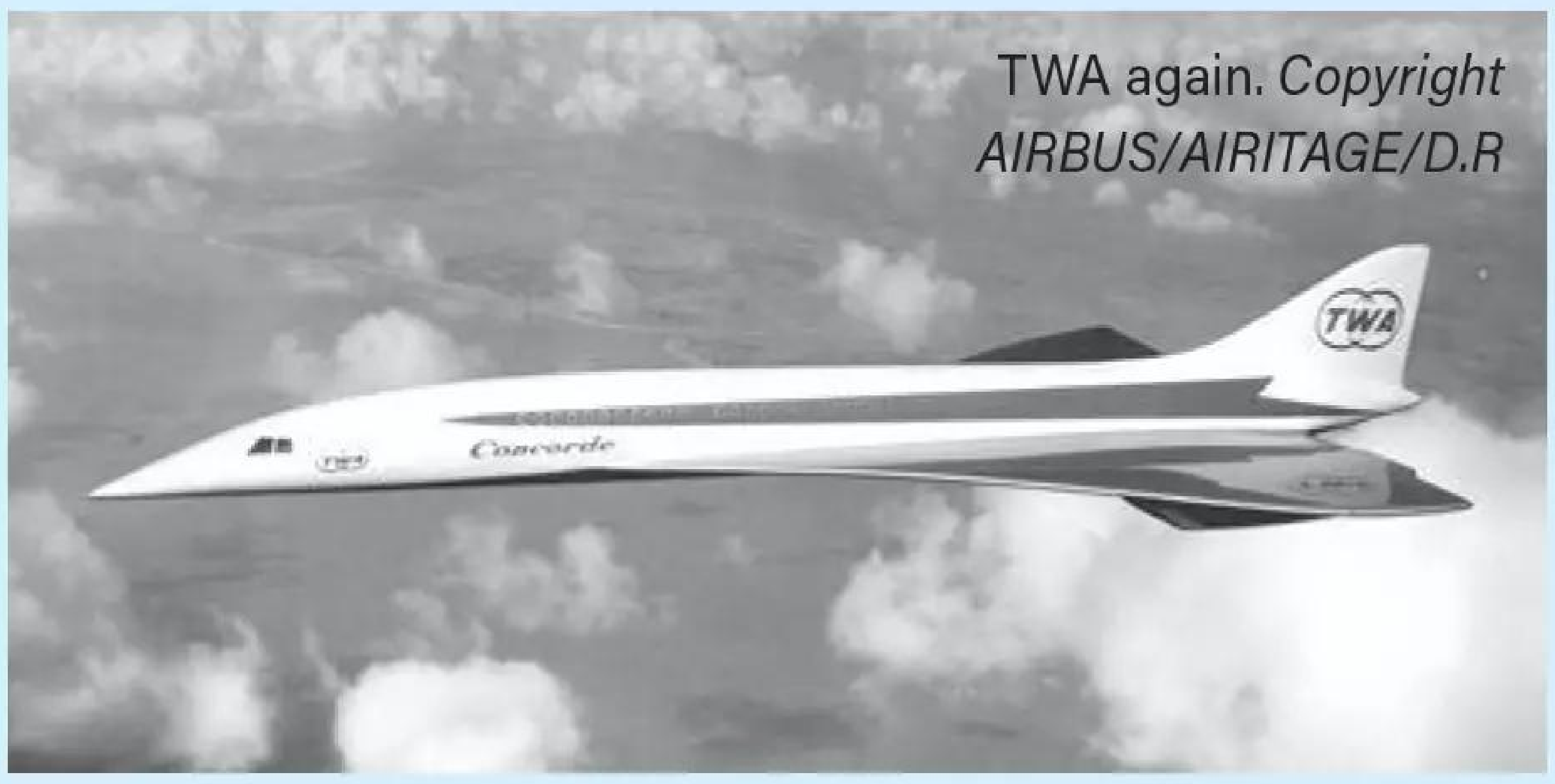

Continental Airlines. *Copyright AIRBUS/AIRITAGE/D.R*


Singapore Airlines.


Middle East Airlines.


TWA (Trans World Airlines).


Pan American.


TWA again. *Copyright AIRBUS/AIRITAGE/D.R*

This selection of images presents a variety of models and artworks of Concorde made during different stages of the aircraft's development. It shows the airliner in the liveries of many potential customers, not all of which placed 'optional' orders. *All BAE SYSTEMS Heritage, Farnborough unless otherwise stated*

However, the manufacturers had some problems getting their home airlines to take the aircraft, in particular BOAC was worried about the cost and wanted Concorde on its own terms. In due course, however, Air France and BOAC did sign the first firm production Concorde contracts on 28 July 1972 with orders for five and four aircraft respectively.

These efforts were backed up by sales tours. On 4 September 1971 Concorde 001 (F-WTSS) left France for a two-week demonstration and sales promotion tour in South America, in the process making its first transatlantic flight; 001 reached Rio de Janeiro via the Cape Verde islands, Cayenne and Sao Paolo. Then between 2 June and 1 July 1972 British Concorde prototype 002 (G-BSST) toured the Far East.

Starting at Fairford this trip took in Athens, Teheran, Bahrain, Bombay, Bangkok, Singapore, Manila, Tokyo, Manila again, Darwin and Sydney in a route which stretched for over 45,000 miles (72,400km). It did bring success in that, after the Shah of Iran flew in the aircraft, three Concordes were ordered by Iran Air. However, it is understood that the black exhaust smoke thrown out by 002 in Japan did not help its prospects there (though production machines were expected to erdicate that problem).

During the en-route flying on the Far East tour the BAC flight test team learnt much. Here, freed from the constant constraints of test flying, they were able to settle down to fly Concorde at Mach 2 in a straight line for periods of an hour or longer, and in the process the aircraft revealed some excellent aspects to its performance along with outstanding reliability. In addition the prototype demonstrated its ability to operate over airline routes with something approaching airline punctuality very well indeed, and this when it was barely half-way through the planned 3,500-hour test programme.

However, during the first half of the 1970s fate presented some obstacles which Concorde just could not overcome. October 1973 saw the start of that year's Oil Crisis when members of the Organisation of Arab Petroleum Exporting Countries put an embargo on oil supplies made to those nations perceived to have supported Israel during the recent Yom Kippur War. This embargo ended in March 1974 by which time the price of oil globally had nearly quadrupled, and so an aircraft which consumed a lot of fuel when carrying a relatively small number of passengers suddenly seemed a bad risk financially.

The Oil Crisis also contributed to a major stock market crash which lasted right through 1973 and 1974, while the unit cost of the aircraft itself had by 1977 reached some £23 million. In addition, new wide-body subsonic airliners like the Boeing 747 were clearly more efficient and economical and presented a much lower risk for airlines, and so during this period the favoured solution moved from higher speed to higher passenger capacity.

These events put a big damper on potential Concorde sales from which they never recovered. As a result, one by one, each of the airlines outside the French and UK national carriers announced that they would not take their 'options' because of the much higher costs and risks now involved. A factor that did not help the manufacturers was that none of the 'options' taken by these overseas airlines incurred any financial penalties if they were cancelled.

THE 1973 SOLAR ECLIPSE MISSION

As an aside, on 30 June 1973 prototype Concorde 001 F-WTSS became involved in a project which highlighted the aircraft's extraordinary speed performance. The aircraft was specially modified with two new rooftop portholes plus observation instruments and equipment for use by scientists wishing to observe a solar eclipse (the Moon's eclipse of the Sun), and as such it was able to chase this phenomenon across North Africa to provide a continuous 74 minute period of observation on board.

Turcat was the pilot and he wrote: "For the first time, an aircraft could embark astronomers and let them view an eclipse for a longer time that any astronomer has ever previously had on Earth. It was necessary to remove all the test installation inside the fuselage to house spectrographs and other equipment, and to open up new holes in the fuselage to allow observation at the Sun's zenith: it was [also] necessary to have full use of the aircraft through the month during which it was converted for the role and then for two months to prepare it for the flight." Turcat added that on the day the aircraft had to reach a rendezvous point with less than 15 seconds of delay and then, one and half hours later, land on a remote airfield short on fuel and with dubious weather conditions.

Concorde 001 was to take off from Las Palmas in the Canary Islands, then head south to Chinguetti in Mauritania to rendezvous with and begin flying inside the Moon's shadow, before finally breaking off to turn south-west and land at Fort Lamy in Chad. A simulation flight was carried out successfully on 28 June, while two days later the aircrew for the real thing comprised Turcat, co-pilot Jean Dabos, plus Henri Perrier, Michel Rétif and Hubert Guyonnet. In addition there was an international team of seven scientists and astronomers on board from France, Britain and USA.

In all five different experiments were carried out and the new portholes in the top of the fuselage made possible clear observations at the Sun's corona, which is only visible to the naked eye during an eclipse. A British scientist on board was Paul Wraith who observed through the side portholes the effect produced by the sudden darkness on oxygen atoms in the Earth's atmosphere. The impetus for this mission came originally from British astrophysicist John Beckman who in 1972 had enquired about the availability of 002 to observe the eclipse, but BAC had turned the idea down. However, a year later Beckman was contacted by French colleague Pierre

Léna who had won Turcat's support for an eclipse chase over a lunch in Toulouse, and Turcat then sold the idea to Ziegler who was happy to support the mission.

A forward fuselage mock-up was built at Abingdon in Oxfordshire complete with representations of the experimental equipment and the cost of fitting out Concorde for this exercise came to £130,000, split between France's official General Delegation for Scientific Research and Technology and Britain's Science Research Council. To review an eclipse in the past expeditions had been made to inaccessible areas of the world to snatch the few precious minutes of totality (the period of time when the Sun's disc is hidden completely), and on many occasions this effort had been frustrated by cloud.

Even with fine observing conditions a total eclipse is never longer than 8 minutes and usually much less. The use of subsonic airliners such as the Boeing 707, flying along the eclipse path at almost half the speed of the shadow, had stretched the available period of observation up to around 10 minutes, but Concorde could match the shadow's speed over the ground of 1,300mph (2,092km/h). As noted the eclipse was chased for 74 minutes after which 001 landed as intended at Fort Lamy, but a hoped-for 85-87 minutes (a planned run of 1,900 miles/3,060km) was prevented by strong headwinds which reduced the aircraft's ground speed. *Flight* magazine reported "as a measure of the effectiveness of the Concorde mission, [this long period] of observation under virtually ideal conditions could be compared with the 129 minutes occupied by all the [other] solar eclipse observations which had taken place during the past 50 years."

POLITICS

Unlike most other civil aircraft Concorde was always exposed to politics. Indeed, there were attempts by the British Government to close the programme down before the airliner had entered service. For example in the autumn of 1964 the Labour Party was elected into power in the UK and brought with it a change in thinking in regard to the joint SST agreement reached with France in 1962 by the previous Conservative Government. Britain was struggling economically and in late October 1964 the new Minster of Aviation, Roy Jenkins, flew to Paris to meet his opposite number and to re-examine Britain's part in the programme.

G-BSST pictured at Athens during the summer 1972 Far East Tour. *BAE SYSTEMS Heritage, Farnborough*

In fact the desire was to withdraw from what was considered to be an expensive 'prestige' project. However, as mentioned, the agreement contained no breakaway clause and so any unilateral withdrawal by either party would prove a complex issue to take through to a conclusion. Subsequently, on 20 January 1965, Jenkins announced that the Concorde programme would continue.

In May 1965 Jenkins added that a production run of "100 Concordes, or perhaps a few more" would need to be sold to get a reasonable return on the research and development costs. At that stage the number of booked positions stood at 45, while BAC and Sud were also anticipating that a combined production rate from their two plants of five aircraft per month (i.e. 60 per annum) would be necessary to meet the expected demand. Another Government document from December 1965 stated that "by March 1973 a production rate of 3 Concords per month is expected."

Again, in March 1974, with now just nine firm orders secured from the two national carriers, another newly elected Labour Government (and in particular Antony Wedgwood Benn) found themselves once more examining Britain's involvement in Concorde, and yet again possible options for cancelling the project came under consideration. Nevertheless, as previously, Britain had to stay with the aircraft and in August Benn cleared the way for the production of 16 aeroplanes. In fact it was estimated at this time that the production losses would amount to some £200-225m. In the end of course only these 16 production Concordes were ever completed, of which 14 were delivered for service use, seven each to Air France and British Airways.

From the British point of view the Concorde programme became pretty insecure again during the late 1970s but this time a change in BOAC chairman in 1981 helped to provide the lifeline. The new chairman was Lord King (John King) who offered new support for the aircraft. In particular he recognised its importance to British Airways, despite the fact that during its early years of service in this airline's hands it had lost money and had consequently attracted criticism as a white elephant. King, however, got British Airways to successfully use Concorde as a tool to win new business customers from other transatlantic competitors. So Concorde survived, and was now allowed to become a symbol of prestige for the UK.

SERVICE CAREER

The year 1975 saw the start of route proving and endurance flying using Concordes G-BOAC and F-BTSC (the latter was in fact Concorde 203 F-WTSC given a special category Certificate of Airworthiness, the switch from the earlier F-W prefix to F-B indicating this transition from trial to certified status). On 28 May 1975 F-BTSC began to explore the following routes – Paris to Dakar, Paris to Rio via Dakar, Paris to Caracus via Lisbon, and Paris to Gander, the object being to provide route-proving and route-training flights with representative loads of passengers.

On 7 July G-BOAC (Concorde 204) began the British endurance flying programme with trips connecting London, Bahrain, Bombay, Kuala Lumper, Singapore, Melbourne, Beirut, Gander and Damascus. But it was January 1976 before Concorde could begin its scheduled commerical flights, starting with routes from London to Bahrain and Paris to Rio de Janeiro (via Dakar) from the 21st of that month. Indeed, G-BOAA of British Airways and F-BVFA of Air France made simultaneous take-offs to ensure that both countries opened their services at the same moment.

However, also in January 1976, the US Congress banned any landings by Concorde in America, primarily from the ongoing protestations concerning the sonic boom, so the longed-for North Atlantic services had to be put on hold. Eventually, and after a great deal of negotiation with the airlines and the manufacturers, William Coleman, the US Secretary of Transportation, gave special permission for the aircraft to fly into Washington Dulles Airport. Consequently, on 24 May 1976 both Air France and British Airways began services into Washington, the Air France and British Airways Concordes concerned making simultaneous landings on parallel runways at Dulles before taxing to their terminal to enable a famous photograph to be taken showing the two aircraft nose-to-nose.

The ban stopping Concorde going into JF Kennedy Airport in New York was lifted in February 1977 on a trial basis, but then New York's Port Authority automatically slapped a new ban on the aircraft at local level. This farcical situation was ended when this ban was raised on 17 October 1977 and so scheduled services from both London and Paris to New York could start at last, the first flights being made on 22 November 1977.

In February 1977 Braniff Airlines gained approval for an interchange agreement which would permit this American airline to extend Concorde services further on to Dallas using Air France and British Airways aircraft but with Braniff aircrew. To make this possible and comply with FAA regulations 10 Concordes, five from each airline, had to be re-registered with American N-numbers. Air France began a Mexico City via Washington service in September 1978, and the Washington to Dallas route was opened in January 1979. However, these could still only be flown over land at subsonic speeds which contributed to both of these additional routes being discontinued in June 1980.

Also towards the end of 1977 British Airways opened a service to Singapore which involved another share arrangement, this time with Singapore International Airlines. This move saw Concorde G-BOAD painted in full Singapore International Airlines colours on its port

Superb head-on view of a production aeroplane. *BAE SYSTEMS Heritage, Farnborough*

side only, with the British Airways scheme retained on the starboard side. However, Malaysia objected to having supersonic flights over the Straits of Malacca and for a period Concorde was banned from its airspace. Although resuming in January 1979, this Far East service came to an end in November 1980, at the same time as did the flights to Bahrain. Air France's Caracas and Rio de Janeiro operations were also discontinued in March 1982.

So it was left to the transatlantic services to keep Concorde active but, with rises in fuel prices and seating limited to 100 first-class passengers, these would never generate further aircraft orders or bring in enough revenue to clear the development costs. Indeed, a British Labour Government review made in February 1979 established that British Airways could never make a profit with Concorde "by ordinary commercial standards". Accordingly £160m of Public Dividend Capital associated with five British Airways Concordes was written off, which in other words meant these aeroplanes now became a gift from the taxpayer to the airline.

In the future British Airways would still have to pay to the Government 80% of any Concorde operating profits, and thanks to the introduction of 'Champagne' charter flights by both BA and Air France the aircraft did begin to make some money. These charter trips, usually lasting under two hours and flown quite regularly over the Bay of Biscay, enabled the general public to experience supersonic flight and they did much to enhance the aircraft's reputation.

During the 1980s and 1990s the service Concordes experienced one or two scares in regard to safety issues, for example in April 1989 when G-BOAF lost part of its rudder when flying at Mach 2. But it was of course the tragic crash and loss of Air France's F-BTSC on 25 July 2000 from a fuel tank fire that brought the beginning of the end. Concorde was grounded and subsequently received a number of important safety modifications. Revenue flights were restarted in November 2001, but in 2003 the two airlines announced that Concorde operations would cease in October of that year. Reduced passenger revenue against a backdrop of increasing maintenance costs proved to be a major factor behind this move.

In fact Air France's last scheduled supersonic flight took place on 31 May 2003, which was a final return flight from New York to Paris. The last British Airways flight came a little later, on 24 October from New York to London, and when the British airline finally withdrew Concorde this brought to a close the world's only supersonic passenger service. The last Concorde flight of all was made just over a month later on 26 November 2003 when one was delivered to Filton. The aircraft in question, G-BOAF, is the centrepiece of the Aerospace Bristol Museum.

It had been intended to keep Concorde in service until 2010, but the decision to retire the aircraft early in 2003 was made because of the cost of keeping operational what were now in fact quite tired airframes. A big worry had been the honeycomb structure used for the intake ramps (or rather a worry about the delamination of their sandwich construction) such that a piece might break off through the failure of the bonding and be ingested into the engines. At the time there was no solution to this because British Aerospace had never opened a replacement programme for these sections. There was also a worry about the 'engine out' problem because if it lost an engine Concorde could not cross the Atlantic flying only at subsonic speed.

Items which had added to the Concorde development cost were the two static test specimens. The stress test specimen set up in France was in fact purposely tested to destruction quite early on in the programme, but in 1980 the second airframe based at RAE Farnborough was still undergoing testing at a cost of several million pounds per year. The objective had been to have this Concorde fatigue specimen fully 'flight cycled', a process which saw the airframe experience the heating and cooling process on every supersonic 'flight'. However, in the end the Farnborough-based test programme was also terminated early and so Concorde was never actually 'lifed', having reached only 9,500 cycles.

By December 1977 the French had disposed of their jigs which removed the country's capability to produce further Concordes. In October 1978 the jigs used to manufacture the British Concordes were taken from the Brabazon Hangars at Filton to go into store at Wroughton in Wiltshire, just in case there might still be the possibility of further orders. However, on 31 December 1980 it was announced that the production phase of Concorde was now over, and in October 1981 the disposal of the stored British jigs to scrap merchants was started.

IN CONCLUSION

Although the Soviet Tupolev Tu-144 supersonic airliner also left its mark, the BAC/Sud Aviation Concorde remains a unique achievement in aviation history as the only successful in-service supersonic transport, though one could argue for hours that had events gone differently then that its 'success' might have gone far further and been more marked.

Nevertheless Concorde's achievements will not be beaten for a very long time. These included for example the combined Concorde fleet being credited with more supersonic flight hours than all the world's air forces put together. While subsonic commercial jet airliners needed some eight hours to complete the journey between New York to Paris, Concorde's average supersonic flight time for the route came to just under 3.5 hours. When the aircraft was flying at 50,000ft (15,240m) there were also no headwinds to delay its arrival, and the aeroplane and its passengers were flying above turbulence.

Concorde's weight would of course fall as it burnt fuel, which meant that the aircraft would continue to climb slowly during its flight, and when it reached its deceleration point around 350nm (650km) from its destination it had often drifted up to an altitude of around 58,000ft (17,680m). At this height the sky is a darker blue, with a slight purplish tint, something which airline passengers had never had the chance to see before the arrival of the SST.

However, breaking so much ground from a technical point of view cost a lot of money, and when this was added to general inflation, a devaluation of the British pound in 1967, the reworking of Concorde into just its long haul version, and the longer time needed overall to complete the aircraft than first anticipated, then the final project design and development cost came to a good deal more than the initial estimates had suggested.

Then in 1973 the dramatic rise in the cost of fuel came at a moment which hit the SST programme perhaps harder than any other contemporary transport project. Finally, noise was the probably the biggest obstacle to true commercial success, but noise coupled with the rise in fuel price at such a key point ensured that Concorde never had the chance to record big production numbers.

On 7 May 1972 Britain's Minister for Aerospace, Michael Heseltine, made a speech about the Concorde programme which included the following: "Concorde is the largest technological project ever to be undertaken in Western Europe. It is a project dramatic, controversial, expensive and pioneered at the very frontier of human capability. I say it is controversial. Every setback is news. Every advance is news, too, but for the inside pages and not the headlines. The grind and patience, genius and effort in Bristol, Toulouse and in the British and French factories, laboratories and offices of hundreds of different companies, will be seen in the context of aviation history as a dramatic step forward. Concorde provides some 26,000 jobs in the UK alone."

He added: "Concorde will more than double the speed of air travel [and it] has done this on its own. Very little of the ground work has been developed by adaptations from the military field. And Concorde has to meet its original targets within very much smaller margins for error than subsonic aircraft. But Concorde is something more than a magnificent technological achievement. Two countries, speaking different languages, with different technical traditions and ways of working and with different administrative procedures, have come together to develop the most advanced and complex of technological projects. Concorde will halve the time it takes to cross the North Atlantic, and will bring about a dramatic shrinking of the globe." Although most of the hoped-for ambitions for the aircraft that were still prevalent in 1972 never came to fruition, many of Heseltine's words still ring true today. ◆

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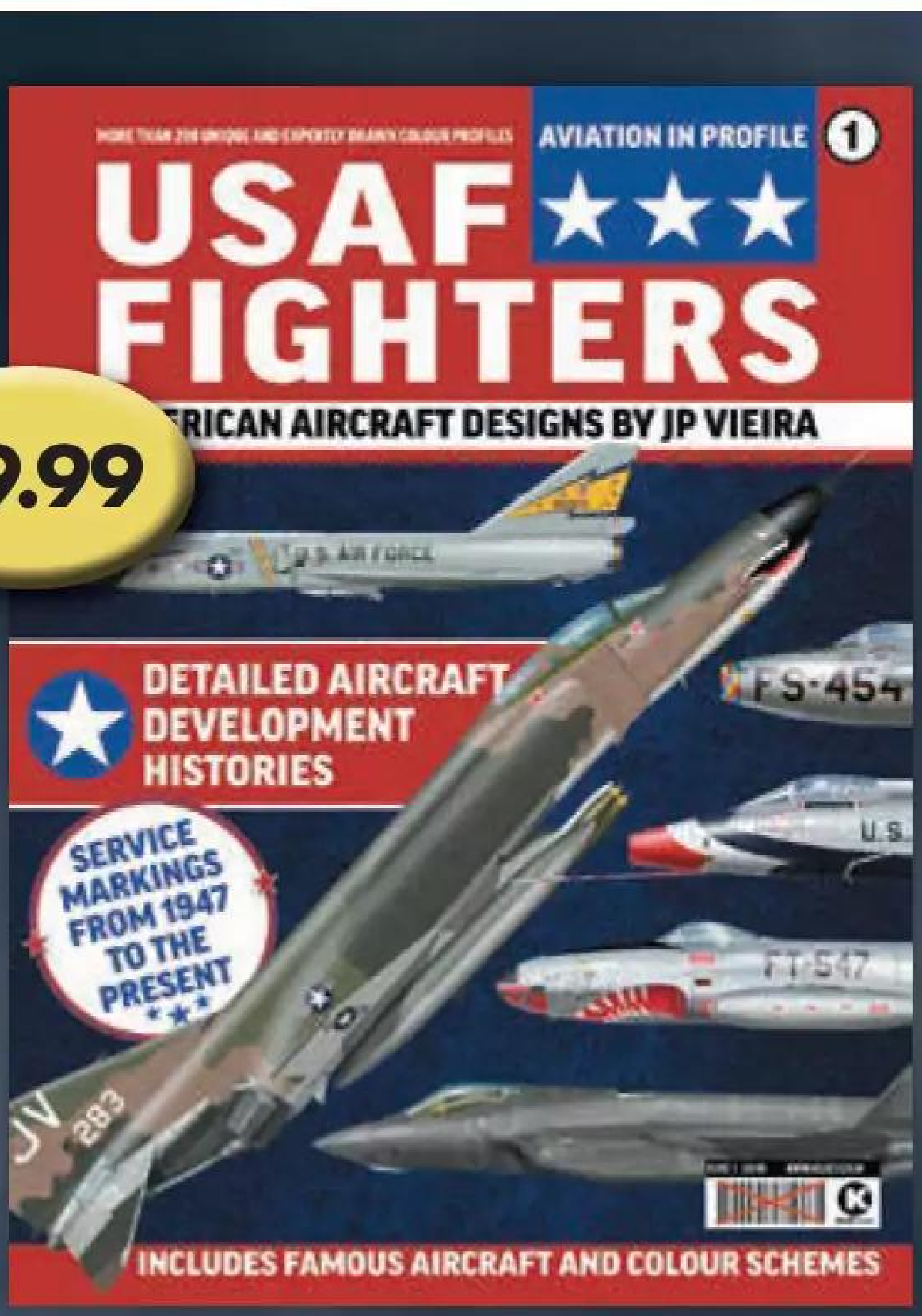
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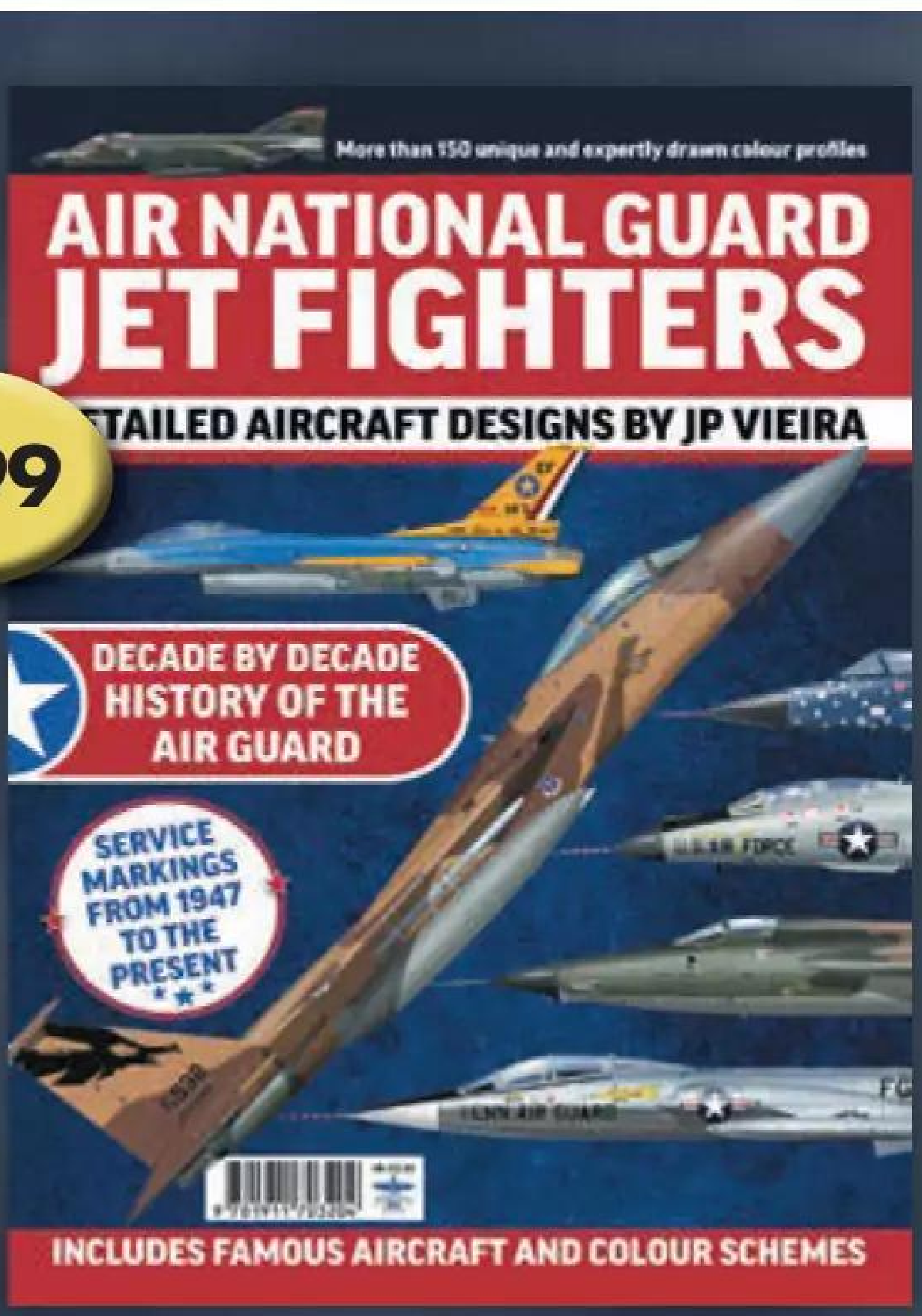
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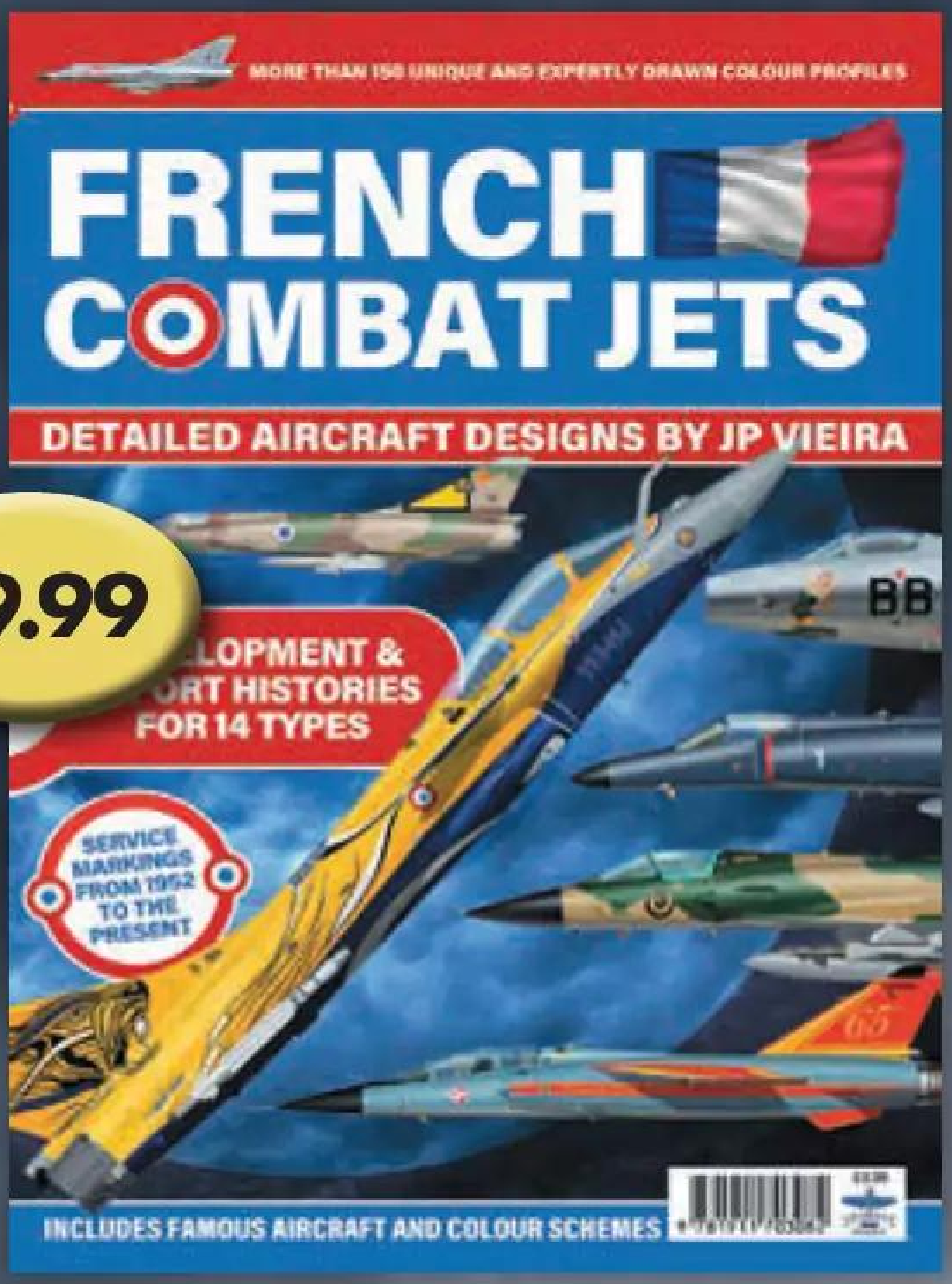
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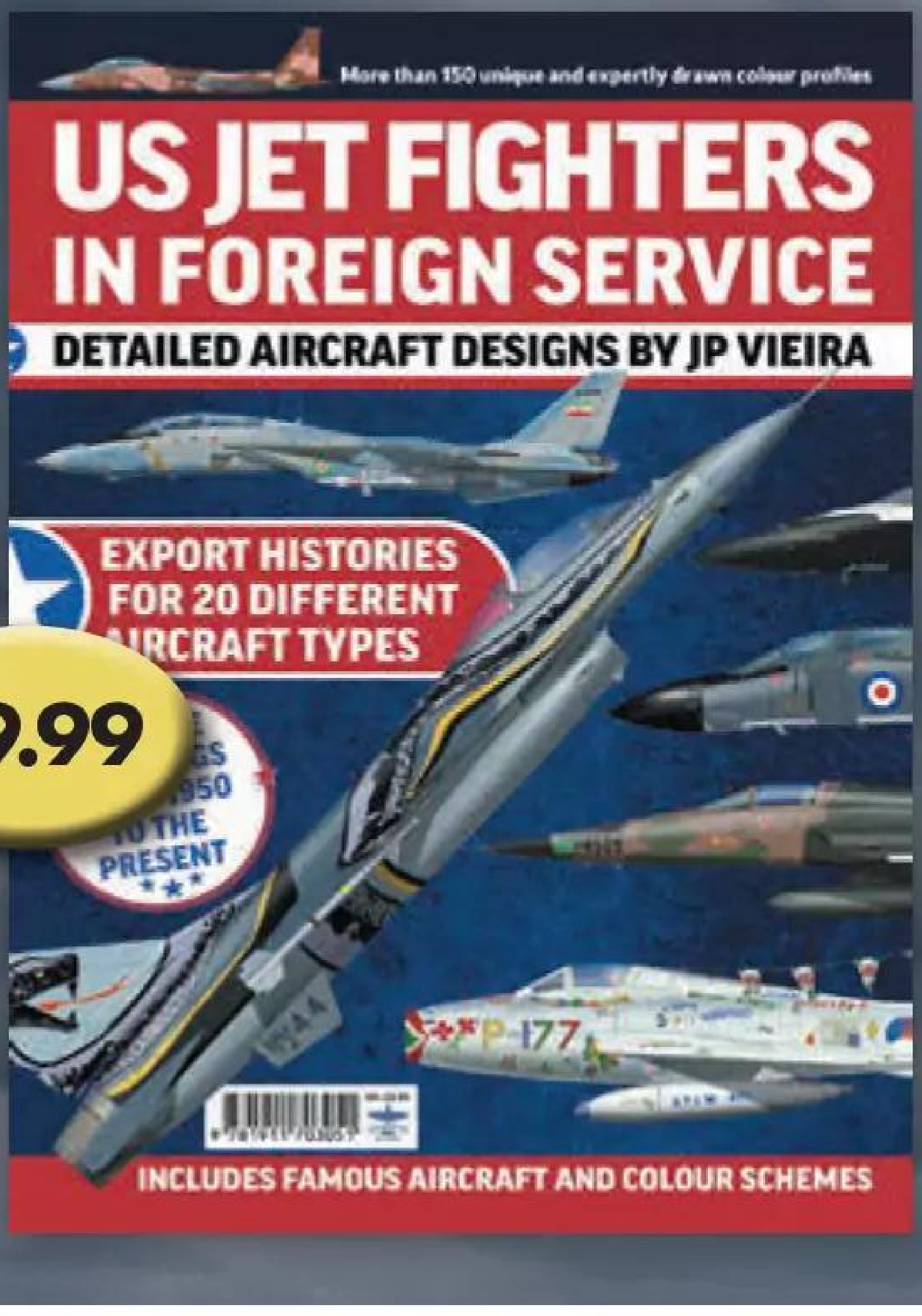
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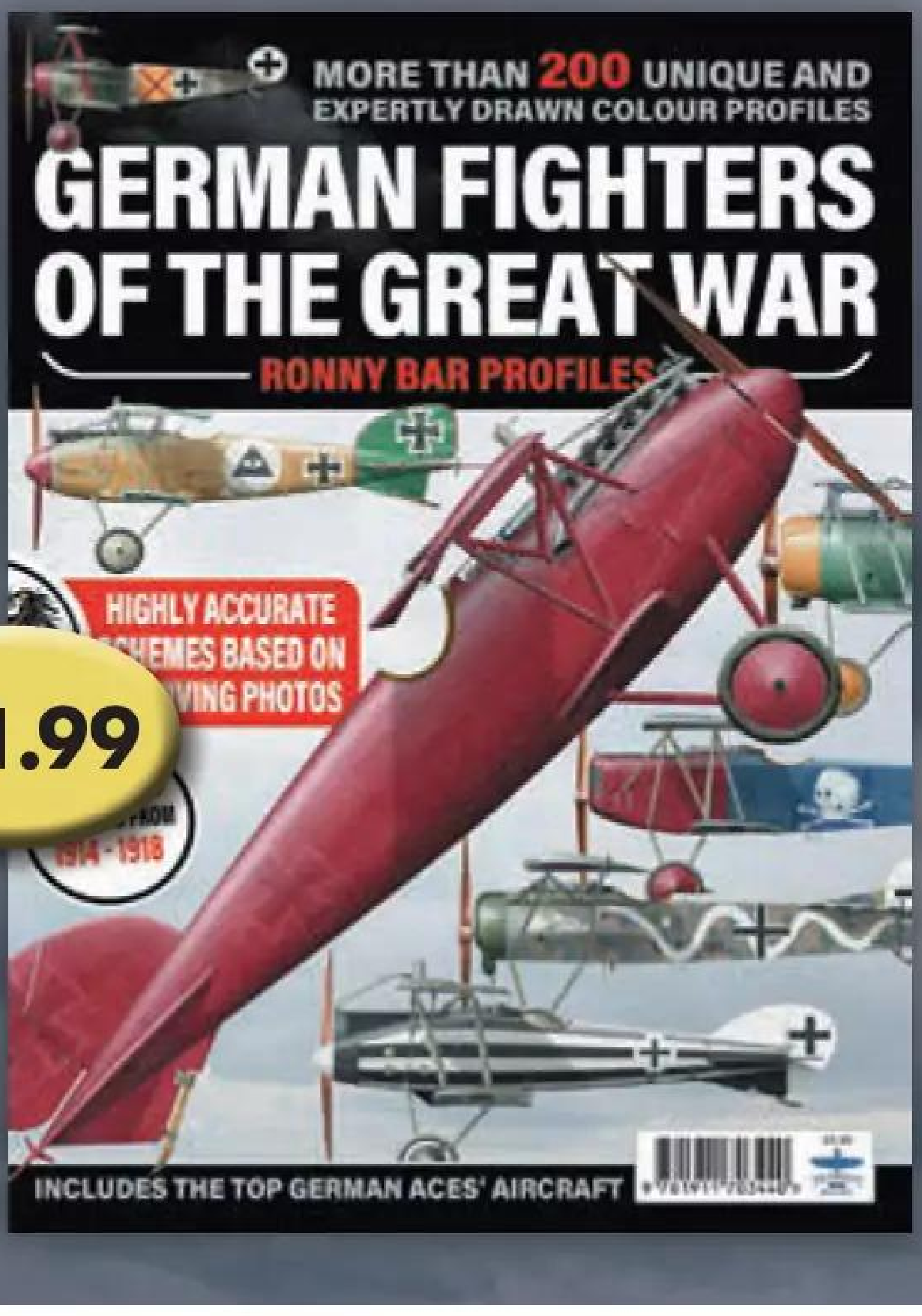
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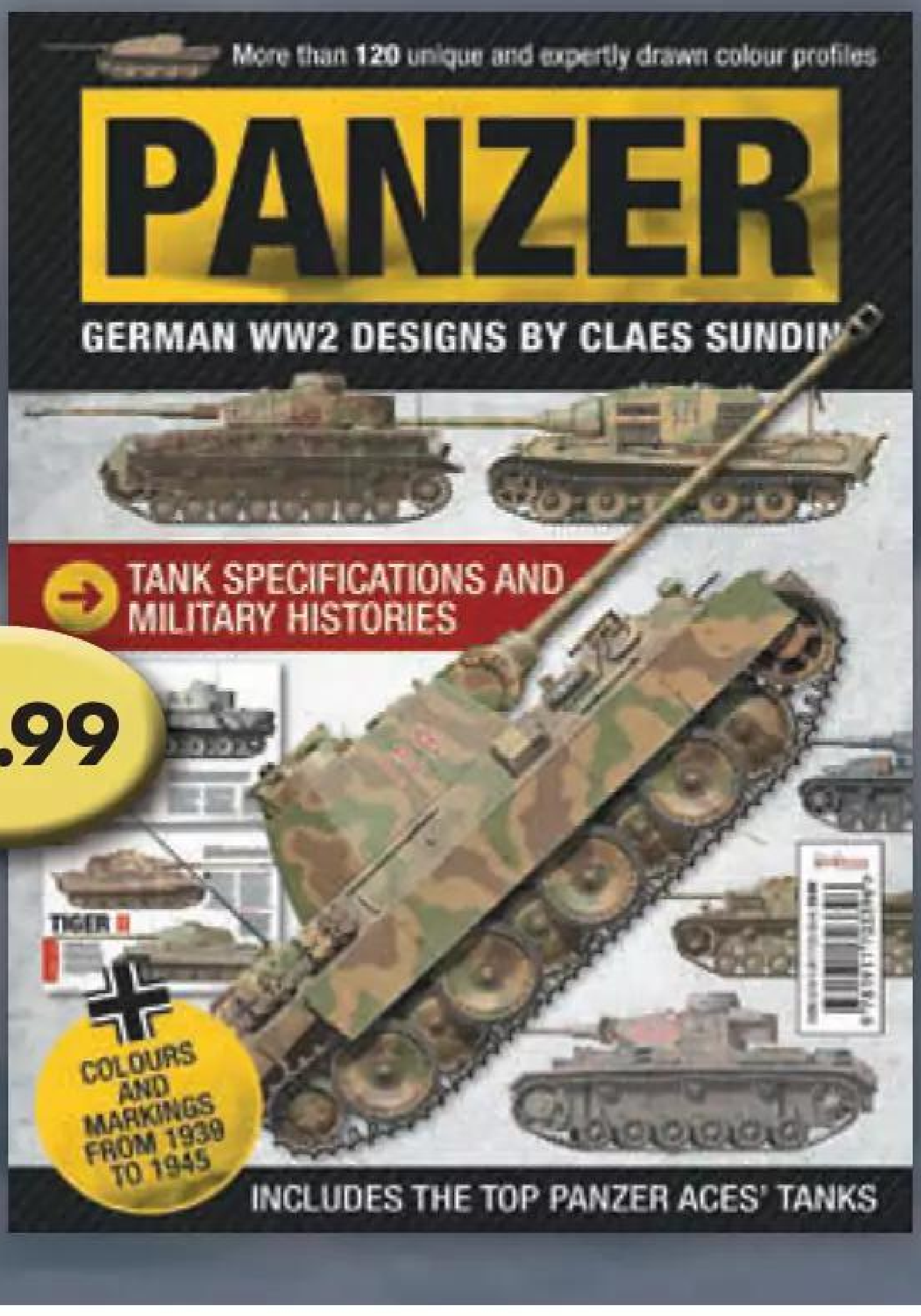
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